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A VESSEL CLASS COMPARISON OF PHYSIOLOGICAL, AFFECTIVE STATE AND PSYCHOMOTOR PERFORMANCE CHANGES IN MEN AT SEA

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16. Abstract

A field study was conducted to compare the influence of vessel motions, characteristic to a 89' Navy experimental Small Waterplane Area Twin Hull (SWATH) vessel, a 95' Coast Guard Patrol Boat and a 378' Coast Guard High Endurance Cutter, upon motion sickness incidence and severity, physiological indices of stress. affective state and psychomotor performance in male Coast Guardsmen.

Psychomotor performance (Navigation Plotting, Complex Counting, Code Substitution, Spoke Test, Time Estimation and Critical Tracking), motion sickness symptomatology, urine output and specific gravity, stress hormone excretion, heart and sweat rate, and subject mood were repeatedly smapled for eight hours a day during three control days at dockside and three days at sea as the vessels steamed side-by-side in four-hour octogonal patterns about a wave measurement bouy. All vessels were instrumented with accelerometers to continuously record vertical, lateral and longitudinal accelerations within the test compartments located below decks amidships and roll, pitch and heave motions at the vessel centers of gravity.

Results show that subjects who were exposed to the motion environment aboard the Patrol Boat as it steamed through sea state 3 conditons suffered severe motion sickness which was associated with physiological stress, slight deterioration in mood and small to moderate decrements in psychomotor task performance. The SWATH vessel although close in size to the Patrol Boat, produced an acceleration environment similar to that experienced aboard the much larger High Endurance Cutter. As a result no motion sickness, stress, mood deterioration or performance task decrements were found aboard either the SWATH vessel or High Endurance Cutter.

408 732

Abstract (cont.)

Changes found in motion sickness symptomatology severity, physiological stress, mood state and task performance aboard the Patrol Boat were examined for relationships between motion sickness severity, accelerometer records and other independent variables. Relationships found are presented and are compared with previous laboratory motion generator and field study findings. Limited recommendations are made with regard to vessel ride quality design critieria.

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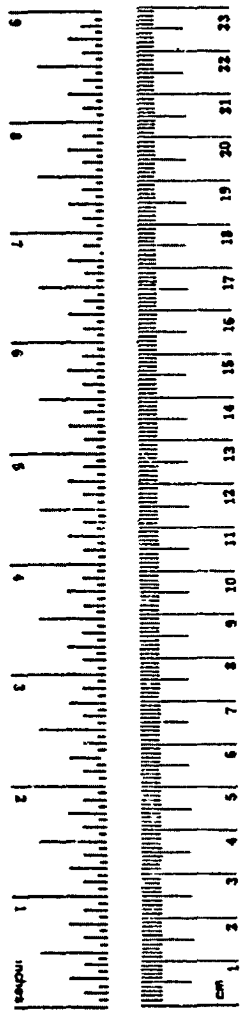
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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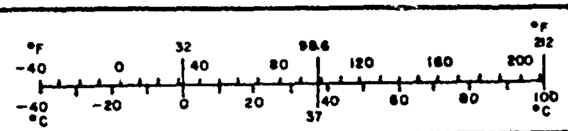
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

The objectives of this study were to examine the effects of actual vessel motions, characteristic to a 89' Navy Small Waterplane Area Twin Hull (SWATH) vessel, a 95' Coast Guard Patrol Boat and a 378' Coast Guard High Endurance Cutter, upon motion sickness incidence and severity, objective physiological indexes of motion sickness and human stress, indexes of mood, and levels of psychomotor performance; to determine if the SWATH vessel design offered measureable advantages in crew habitability and performance over comparably sized and larger monohull designs; and to make comparisons between the experimental results and unvalidated laboratory findings.

Psychomotor performance (navigation plotting, critical tracking, code substitution, complex counting, time estimation and Spoke test), motion sickness symptomatology, urine output and specific gravity, stress hormone excretion (catecholamines and 17-hydroxycorticosteroids), heart and sweat rates, and subject mood were repeatedly sampled from 18 young male Coast Guardsmen during six consecutive eight hour days spent aboard the three vessels. Each subject was exposed to each vessel while it was dockside and on a seperate day when it was at sea. During the periods spent at sea the vessels steamed together in four-hour octogonal patterns about a wave measurement bouy. All vessels were instrumented with accelerometers to continuously record vertical, lateral and longitudinal accelerations within the test compartments located below decks amidships. Roll, pitch and heave motions were also recorded at the nearby vessel centers of gravity.

Results showed that as the vessels steamed through sea state 3 conditions, no motion sickness, significant stress, mood deterioration or performance decrements were experienced aboard the comparably stable High Endurance Cutter and smaller SWATH vessel. Exposure to the considerably more dynamic environment aboard the patrol boat led to severe motion sickness, reduction in urine output, elevations in urine specific gravity and urinary excretion of corticosteroids, slight deterioration in subject mood, and small to moderate decrements in all performance tasks measured. In general, physiological and psychological indexes of stress and declines in subject performance were significantly correlated to motion sickness severity and vessel motions which were correlated with motion sickness. Vessel motions, or motion characteristics, unrelated to motion sickness were not significantly correlated with the aforementioned subject responses. Relationships found between motion sickness onset and severity and vessel motion records indicate that vertical acceleration characteristics, not rolling or pitching motions, are predominantly responsible for motion sickness onset and severity. Motion sickness severity increased in a nonlinear

manner as patrol boat vertical motion frequencies declined to the limit of 0.20 Hz. Increasing the amplitudes of vertical motions at any given frequency led to additive increases in motion sickness severity.

In sea state 3 conditions the SWATH vessel produced a significantly more stable environment than that of a comparably sized monohull; a motion environment comparable to that found aboard the substantially larger High Endurance Cutter. As a result of the ride quality aboard the SWATH, subjects did not experience motion sickness or the associated antiduresis, increased adrenalcortical activity and slight mood deterioration found aboard the patrol boat. Performance task decrements found aboard the patrol boat, which were greatest in tasks which were complex or required sustained levels of effort or attention, were also avoided.

Physiological and mood responses to the patrol boat's provocative motion environment, as well as their interrelationships, concur with previous findings obtained in the laboratory using simple motion generators. The breadth of performance decrement found aboard the patrol boat in this experiment is consistent with a previous study performed at sea but not with laboratory ship motion simulator findings to date. The lack of agreement between field and laboratory studies in human performance to date may simply reflect more demanding testing paradigms and more sensitive tests used in the field studies.

Based upon the findings of this study it is clear that increased vessel stability afforded by the SWATH design prevented motion sickness and stress, and permited measureably better performance than did a comparably sized monohull in sea state 3 seas. It is recommended that presently meager very low frequency whole body vibration exposure data be augmented with additional experimentation using a multiple degree of freedom ship motion simulator. Simulators offer greater experimental control and manipulation of the force environment and, with periodic validation, are capable of efficiently providing vessel ride quality design criteria for ad hoc vessel stabilization systems and future vessel design.

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LIST OF ABBREVIATIONS

ADH	Antidiuretic Hormone
CTT	Critical Tracking Task
GGAS	General Gravity Adaptation Syndrome
17-OHCS	17-Hydroxycorticosteriods
MACL	Mood Adjective Checklist
MSI	Motion Sickness Incidence
MSSS	Motion Sickness Symptomatology Severity
rms	Root Mean Square
SS	Sea State
SSP	89' Navy Semi-Submersible Platform
SWATH	Small Water Area Twin Hull
WHEC	378' Coast Guard High Endurance Cutter
WPB	95' Coast Guard Patrol Boat
λ_c	Critical Tracking Task Bandwidth Limit
g	Gravity
n	Number of subjects
$\bar{\Delta}$	Mean change

GLOSSARY

affective state	emotional or mood state
antidiuresis	the suppression of secretion of urine by the kidneys
cognitive	having to do with thought processes
diaphoresis	perspiration or sweat
emesis	the act of vomiting
etiology	the study of cause
gluconeogenesis	the formation of sugar by the liver from noncarbohydrate molecules
glycogenolysis	the splitting up of glycogen into dextrose
heave	vertical oscillatory motion of a specified point in a vessel, usually the center of gravity
labyrinth	the internal ear, made up of the vestibule, cochlea and semicircular canals
nausea	a distressing feeling that vomiting is imminent
paradigm	a pattern, design or model
pitch	an angular component of the oscillatory motion of a vessel, about a transverse axis
proprioceptor	a specialized nerve ending in muscles, tendons and joints which is sensitive to changes in tension of muscle or tendon, and therby provides information regarding body movements and position
psychomotor	pertaining to motor responses to cerebral or psychic activity
roll	the angular component of the oscillatory motion of a ship measured about a longitudinal axis
root mean square	the square root of the mean squared error

tachycardia .... abnormally rapid heart rate

vertigo .... dizziness

INTRODUCTION

Most previous investigations of the influences of very low frequency whole body vibration influences upon motion sickness incidence and severity, physiological correlates to motion sickness, psychophysiological stress and psychomotor performance have been performed in the laboratory. Use of one or two degrees of freedom oscillating platforms, slowly rotating rooms, Barany chairs and other mechanisms designed to generate relatively simple whole body motions have shown motion sickness to be a frequency and acceleration specific vestibular-dependant malady associated with a number of physiological changes. These include, increased secretion of antidiuretic hormone, glucocorticoids and catecholamines, diaphoresis, and tachycardia during the emesis episode. Yet motion sickness and associated physiological changes observed during exposure to simple motion environments in the laboratory have not been validated aboard seagoing vessels where whole body motion exposures are significantly more complex and random in nature.

Over the past 30 years of laboratory based, very low frequency, whole body acceleration research, only a few psychomotor performance tasks out of the many investigated showed decrements during exposure to whole body motions or

resultant motion sickness. With recent independent reports of psychomotor performance decrements in a variety of tasks examined aboard vessels at sea, concern over the lack of shipboard validation of ship motion simulator findings has increased.

Whether the psychomotor performance results obtained from a limited number of field studies are truly contradictory to a vast number of laboratory findings is difficult to determine. No motion records were made during the studies at sea which would permit comparisons of the force environments endured. In addition, many of tasks which showed significant performance decrements at sea were not examined in the laboratory. Certainly the applicability of laboratory findings to uncontrolled complex whole body motion environments will be suspect until experiments are conducted aboard vessels instrumented to record the motions presented to subjects and replication of laboratory studies are made for comparison.

The opportunity to perform such a study arose during the Spring of 1978 when the United States Coast Guard, with the cooperation of the United States Navy, performed a series of operational sea trials to evaluate the seakeeping capabilities of three very different classes of vessel; a 378' WHEC, Coast Guard High Endurance Cutter; a 95' WPB, Coast Guard Patrol Boat and an 89' SSP, Navy Semi-Submersible Platform also known as a Small Waterplane Area Twin Hall (SWATH) Vessel. These vessels

vary not only in size, speed, endurance and possible mission profile but are predicted to yield different motion responses to equivalent sea states.

As the vessels were extensively instrumented to record their motions during the sea trials, and the operation called for side-by-side steaming of patterns designed to induce regular changes in the motion response of the vessels as they progressed through measured sea conditions, the opportunity to investigate the effects of ship motion upon a number of physiological, affective state and psychomotor performance variables was seized.

The objective of this study was to examine the influence of actual ship motions, characteristic to three very different classes of vessel, upon motion sickness incidence and severity, objective physiological indices of motion sickness and human stress, affective state and psychomotor performance in young male Coast Guardsmen. Selection of a physiological, affective state or psychomotor performance indices for study was based upon their redundancy with respect to results obtained under previous laboratory motion generator environments, their potential utility in objective measurement of motion sickness severity or psychophysiological stress in whole body acceleration and their economy, ease and acceptability of collection during a week-long human performance experiment.

All significant changes in measured human response to the motion environment were examined for direct and indirect (i.e., motion sickness) influences of the vessel motions endured and results were compared with previous laboratory and field study results.

BACKGROUND

Vessel Motion and Motion Sickness

Motion sickness, sometimes referred to as kinetosis, is a familiar malady to those whose occupation, or avocation, expose them to very low frequency whole body motions aboard vessels at sea. Whether an individual has, or will experience motion sickness depends upon the health of his vestibular system, the amount of recent exposure to similar motion environments, the characteristics of the motions experienced, and the length of the motion exposure (Money, 1970).

The prevalence of motion sickness incidence implied above is supported by studies with small marine craft which induced frank motion sickness (emesis), depending upon severity of sea state, in 11 to 70% of the passengers and crew (Holling et al., 1944; Tyler and Bard, 1949; Llano, 1955). Larger vessels, such as passenger ships and naval destroyers making winter crossings of the Atlantic Ocean, have produced similar magnitudes in incidence during the first few days of the crossings (Bruner, 1955; Chinn, 1956; Chinn, 1963). Although such studies do not permit an accurate estimate of susceptibility in the general population, examination of histories taken from a population of

college students showed 90% of the students had experienced motion sickness at one time or another (Reason, 1967).

Motion sickness is not only widely experienced but is easily recognized. It is characterized by the development of facial pallor, cold sweating, drowsiness, nausea and ultimately by emesis (Desnoes, 1926; Flack, 1931; Maitland, 1931; McEacher et al., 1942; Hemingway, 1944; Tyler and Bard, 1949; De Wit, 1953; Schwab, 1954; Crampton, 1955; Taylor et al., 1960; Clark and Graybiel, 1961; Kennedy et al., 1965; Whiteside, 1965). Such symptoms are generally reliable and exhibit a sequential pattern during onset. Drowsiness, pallor and cold sweating usually precede nausea which intensifies to the point of emesis (Hemingway, 1944; Crampton, 1955). A few individuals, however, may reach the emesis stage so rapidly that nausea and other preliminary symptoms are not encountered prior to emesis (Maitland, 1931; Loftus, 1963). Exceptions at the other extreme are cases where individuals suffer severe and protracted states of nausea without emesis, or who fail to develop the nausea and vomiting syndrome altogether (Reason and Brand, 1975).

Due to individual idosyncrasies mentioned, and the possibility for other pathological conditions to manifest similar symptoms, reliance upon only the aforementioned "cardinal" signs and symptoms in determining the onset and severity of motion sickness can be unwise. Fortunately,

additional indices do exist for substantiation of the syndrome and its progress. Such indicants, although exhibiting a greater degree of individual variability, provide not only confirmation of the syndrome but offer greater precision in scaling its severity within the individual (Kennedy et al., 1965; Miller and Graybiel, 1970; Wood, 1970; Wiker et al., 1979a). The additional indicants range from gastrointenstinal symptoms (e.g., epigastric awareness, burping, increased desire to move bowels) to changes in affective state (e.g., anxiety, depression, apathy) and neurological state (e.g., headache, dizziness, vertigo).

Navy scientists, searching for an experimental endpoint which would spare test subjects from the rigors of vomiting during vestibular research, developed a motion sickness symptomatology questionnaire and severity scaling system (Graybiel et al., 1968a). The technique was successful as it required only simple self-assessments of familiar symptoms and, although symptomatology is somewhat variable from individual to individual, the progress of the syndrome was found to be reliable and characteristic within the individual.

Use of the scaling system allows appropriate weighting of symptoms and their transformation into numerical scores for inclusion in statistical analyses of within subject experimental data. The method has been successfully employed in antimotion sickness drug therapy evaluation (Wood et al., 1966)

and motion sickness incidence studies aboard vessels at sea (Kennedy et al., 1972 and Wiker and Pepper, 1978).

Although recognition and measurement of motion sickness has enjoyed practical success, its etiology continues to spur controversy. A major etiological advance was made in the late 19th century when a ship's physician discovered deaf mutes to be immune to seasickness. Believing congenital damage to the auditory fraction of the labyrinth to be frequently associated with damage to the nonauditory apparatus, and vessel motions to be predominantly angular rather than translational in nature, he attributed seasickness to an irritation or overstimulation of the semicircuar canals (Irwin, 1881). This somewhat circumstantial indictment of the vestibular apparatus did not receive experimental scrutiny until the study by Sjoberg in 1929.

Sjoberg, using a crane to induce vertical oscillatory motions in an elevator car, examined motion sickness susceptibility among normal and deaf humans as well as normal and bilaterally labyrinthectomized dogs. His findings confirmed immunity among deaf individuals, but more importantly demonstrated that confirmed bilateral destruction of the labyrinths led to permanent and complete immunity in once susceptible dogs. Sjoberg's work and other independent reaffirming studies (Johnson et al., 1951; Money and Friedberg, 1964; Kennedy et al., 1965) have led to general agreement as to

the requisite involvement of the vestibular system in genesis of motion sickness.

Disagreements remain, however, as to the type of vestibular transduction (e.g., otolith or semicircular canal stimulation), and where or how the transduced vestibular output interacts with other sensory input to produce motion sickness; the frequency and acceleration characteristics of the motion environment which are most or least provocative; and whether motion sickness is purposeful or pathological.

Arguments for otolithic causation stem from Sjoberg's work and the work of many others who have experienced little difficulty in producing motion sickness with vertical translational motions (Alexander et al., 1945a, b, c, d, e; Alexander et al., 1947; Alexander et al., 1955; O'Hanlon and McCauley, 1974; McCauley et al., 1976).

A recent experiment examined the effects of adding angular acceleration components (e.g., pitch and roll) to vertical translational acceleration. No significant changes in emesis incidence were found between vertical accelerations alone and combined translational and angular conditions (McCauley et al., 1976). The testing paradigm, however, required the heads of the subjects to be restricted in support device to permit accurate assessments of head and body movement. Restriction of head movement in prior swing and aircraft studies has been reported to be effective in reducing motion sickness incidence

and severity (Johnson et al., 1951; Johnson and Mayne, 1953); thus, the contribution of the added angular accelerations as well as the overall magnitude of emesis incidence may have been underestimated.

Additional evidence for otolithic causation comes from objective studies of ship motion which show a predominance of translational rather than angular accelerations (Sjoberg, 1970), and reports of motion sickness relief with adoption of the supine position (Manning and Stewart, 1949; Brunner, 1955; Isaacs, 1957). Theoretically, adopting the supine position should reduce otolith stimulation.

Though such evidence certainly argues well for otolith involvement in motion sickness, no definitive experiment demonstrating otolith responsibility can be found.

Supporters of semicircular canal causation believe linear acceleration environments produce angular accelerations of the head which are ultimately responsible for the sickness. Manning, 1943, found vertical accelerations unable to provoke motion sickness when head restraint was employed. Yet motion sickness occurred when subjects were exposed to equivalent vertical accelerations under angular acceleration conditions (swings). Fraser and Manning (1950) also found that vertical accelerations were unable to produce the magnitude of illness seen in swings producing equivalent vertical linear acceleration components.

The most convincing evidence for semicircular canal genesis of sickness comes from the work of Money and Friedberg in 1964. Using a two-pole swing, 57 susceptible dogs were exposed to cyclic angular accelerations for a period of 25 minutes or until first emesis. Each animal was exposed once a week for four consecutive weeks with time to first emesis serving as the criterion.

Upon completion of pretests, otolith and semicircular canal function exams were performed after which the animals were randomly assigned to one of four experimental surgery groups; bilateral labyrinthectomy, surgical plugging of all six semicircular canals, surgical plugging of fewer than six canals, and a placebo group which underwent a sham operation. Surgical goals were confirmed by postoperative vestibular function tests. Postoperative experimental swing tests were then conducted for 75 minutes or until first emesis for a period of four weeks following recovery.

Results showed total immunity in bilaterally labyrinthectomized animals as well as in those which possessed nonfunctional semicircular canals. Blockage of fewer than all six canals led to reduced susceptibility while the placebo group exhibited no changes.

Such results support the idea that the semicircular canals are involved in motion sickness genesis with rotational or angular acceleration environments; however, the evidence does

not rule out otolitic involvement in predominantly linear acceleration systems.

Motion sickness incidence is clearly dependent upon a functional vestibular apparatus, yet other sensory systems appear to play a role in its genesis.

Benfari (1964) observed presentation of "cinerama" type films led to vertigo and nausea in theater patrons; particularly during scenes which utilized rapid shifts in background scenery.

Miller and Goodson (1960) investigated the onset and severity of motion sickness aboard a fixed-base Bell 2-FH-2 helicopter simulator. The simulator consisted of an actual cockpit display and assembly, a computer system to operate the projection system, and a wide screen multiple projection apparatus. The projection apparatus provided a moving terrain and horizon display in excess of 260° azimuth and 75° elevation central to the pilot's field of vision.

The apparatus simulated flight response to aircraft control movement by altering visual cues such as terrain and horizon angle, increasing terrain passing velocity or changing terrain magnification and horizon elevation to indicate altitude. Use of the simulator provided dramatic changes in the visual surround while the body remained relatively immobile.

Motion sickness questionnaires completed at the end of training "flights" showed 78 percent of all pilots tested (n=36) experienced acute motion sickness. Moreover, pilots with the greatest amount of actual helicopter flight time suffered the most rapid and severe cases of sickness during the simulated flights. Vertigo was reported to be most severe when pilots lost control of the "aircraft" leading to increasingly erratic and exaggerated visual presentations. Finally, the sense of vertigo and nausea often returned, or increased in severity, upon exit from the simulator following relatively long "flights".

The most rigorous examination of the importance of visual input in motion sickness genesis is provided by Dichgans and Brandt in 1973. Visual and vestibular cues, as well as their interactions, were studied using a Barany chair and a rotating cylindrical drum enclosure for visual surrounding presentation. Subjects were strapped into the chair with their heads fixed so that only a 45° side-to-side head movement could be achieved. The chair sat within a cylindrical drum housing which was painted with vertical alternating black and white stripes subtending 7° of visual angle. The chair and drum could be rotated separately, simultaneously, at different speeds or in different directions while the visual field or surroundings were masked.

Subjects were exposed in random order to either a rotating chair with no visual cues, a rotating visual surrounding without chair motion or a combination of simultaneous chair and surrounding rotation. During the experimental conditions subjects were to move their heads side-to-side upon command while making magnitude estimations of vertigo, nausea and perceived body tilt based upon experiences during an initial controlled stimulus run. Additional physiological data such as blood pressure and galvanic skin response (GSR) were taken along the number of head movements required to reach emesis. No differences were found between purely visual conditions, the rotating chair or combined movement conditions with regard to blood pressure or GSR changes. However, emesis incidence associated with only visual input was somewhat less than that of chair rotation or coupled conditions. Simultaneous rotation of the chair and visual surrounding yielded the highest rate of illness with severity declining as surrounding movement was slowed to a stop. Furthermore, both chair and visually induced sickness increased with the increase in rotation rate ($r = .79$, $p < .01$).

Various restrictions of the usual field showed that wider presentations led to greater sickness severity under visually induced conditions ($r = .78$, $p < .001$). At the same time, masking the center of the visual field had no effect upon any

variable measured; thus, indicating that the periphery of the retina plays the central role in visually induced sickness.

The evidence not only etiologically implicates the visual system with motion sickness onset, but is co .gruent with a theory which states that the development of motion sickness results from establishing disagreements, or neural mismatches, between two or more sensory inputs (e.g., vestibular, visual and possibly proprioceptors) which have previously established correlations. The theory, originally developed by Claremont (1930) and recently championed by Reason (1970; Reason and Brand, 1975), argues that sensory information is constantly integrated and, along with learned sensory correlations, is evaluated in the higher centers of the central nervous system. Generally, sensory input is highly correlated; that is, visual field shifts due to head movements are corroborated by parallel inputs from the vestibular and proprioceptor systems.

According to the sensory conflict theory, a susceptible organism subjected to an unusual motion or a visual environment which elicits conflicting sensory input may experience motion sickness if the sensory input discrepancies are large enough. If motion sickness occurs in response to an unusual visula or inertial environment, and the situation remains relatively constant, then sickness wanes as neural adjustments are made and sensory input correlations are reestabl. hed. Once sensory input rearrangement occurs under dynamic environmental

conditions, rapid return to a stable environmental condition may lead to a return of sensory mismatch and motion sickness (Miller and Goodson, 1960).

Several previously perplexing phenomena associated with the motion sickness syndrome can be accounted for by the sensory conflict theory (Reason and Brand, 1975). The most compelling aspect of the theory may lie in its provision of a basis for a hypothesis that motion sickness is not a pathological condition but rather a natural selective defense mechanism. Treisman (1977) hypothesized that motion sickness is not a side effect of our advancing technology but rather an evolutionarily developed defense mechanism against toxin ingestion. Support for such a hypothesis is based upon circumstantial evidence.

Treisman points out that motion sickness is a phenomenon which is widely reported throughout the animal kingdom. Its incidence has been reported in all primates examined, horses, cattle, sheep, dogs, several species of birds and even in fish (Money, 1970).

Second, assuming that the sensory conflict theory is valid, any pathological condition or pharmacological agent capable of producing sensory disturbances, ataxia or disruptions in normal sensory input would be expected to produce symptoms of nausea and emesis. Many pathological conditions and chemical agents which disturb sensory processes are

associated with nausea and vomiting (e.g., Meniere's Syndrome, alcohol, glaucoma, lead ingestion).

Finally, he argues that although unselective feeders may reject toxic substances by smell, taste, or alimentary chemosensation, many substances, such as some neurotoxins, fail to be sensed and are absorbed. Such toxins may act upon the central nervous system, thus, disturbing input or processing of sensory information. Such disturbances may produce a sufficient sensory conflict or decorrelation condition which in turn promotes emesis, sweating, increased salivation, and defecation in an effort to rid the body of the harmful substance.

Treisman points to the differences found in motion sickness susceptibility associated with age and sex and attributes such differences to food gathering activity. Infants, who do not search for food and rely upon breast milk, are not generally susceptible to motion sickness. Adolescents, who are not likely to be skilled in food selection, or aging adults with failing near field vision, are generally more susceptible to motion sickness than young adults. Women, who breast feed and who traditionally have been charged with the selection and gathering of food, appear to be more susceptible than males.

Certainly, more research is necessary before any reliance can be placed in such theories. Yet these theories along with the results of the previously discussed studies indicate motion

sickness is a multifaceted problem which may require several different approaches toward its elimination, or mitigation, aboard present and future transportation systems.

Drug therapy approaches, which have drawbacks in the form of physiological and psychomotor side effects, have been effective solutions in many cases for short-term and infrequent exposures to provocative stimuli which are difficult, or impractical, to control through engineering methods. Effectiveness of engineering control measures (e.g., hull design or post hoc vessel stabilization systems) or administrative control measures (e.g., ship handling strategies, limitations for operation orders or personnel selection) has been limited by the slow development of reliable frequency and acceleration profiles responsible for motion sickness incidence.

Although the debate over vestibular endorgan involvement and other sensory influences upon motion sickness incidence and severity remains unresolved, there is little doubt of the importance of the vestibular system. Given the vestibular apparatus's prime function of detection of head movement and orientation, researchers have sought to resolve the qualities, or characteristics, of provocative motion environments which are necessary for effective engineering controls.

Using an elevator car, Alexander et al. (1945a, b, c, d, e), examined the effects of vertical frequency and acceleration

upon motion sickness incidence. Numerous experiments with a "wave machine" demonstrated motion sickness incidence to be frequency and acceleration dependent. The lowest frequency condition examined (0.27 Hz) was found to be significantly more provocative than higher frequencies tested. Furthermore, higher acceleration levels appeared to be more effective in producing sickness than lower levels examined.

Such pioneering studies, however, suffered from certain limitations. First, subject exposure times were relatively short. Second, the wave forms studied were essentially square waves whereas ships generate motions which are more sinusoidal in form. Third, although frequency changes were evaluated under constant acceleration conditions, no attempts were made to investigate the influence of varying acceleration levels in a systematic manner. Finally, the frequencies examined were generally higher than those seen aboard the majority of ships.

With these criticisms in mind, Hanford et al. (1953), attempted to correlate motion sickness incidence aboard a troop ship making an Atlantic crossing with vessel motion recordings of pitch, roll and heave. No significant correlations were obtained between seasickness incidence and vessel motions data during the three days of data collection.

Several factors may account for the lack of correlations in the above study. Subjects were allowed to roam about the ship at will, making accurate exposure histories impossible to

obtain. Second, ship motions were recorded only during the first five minutes of each consecutive 30 minute data collection period. (Generally, considerably more than five minutes are required to obtain statistically reliable ship motion measures.) Third, the motions in a majority of the ship's compartments were estimated rather than directly measured. Finally, the vessel motion records taken during the first five minutes of each half hour were correlated with nonsimultaneous subject observations.

Another nonlaboratory study compared motion sickness symptomatology aboard C-121, C-130 and P-3 Navy aircraft penetrating hurricanes (Kennedy et al., 1972). Aircraft motions were recorded with linear and angular accelerometers during the flights. Due to the low sensitivity of the recording equipment it was not possible to evaluate accurately the magnitude of accelerations experienced; however, frequency analysis showed the aircraft which possessed the highest degree of illness also possessed the lowest frequency of vertical oscillations (e.g., 0.42 Hz vs. 0.83 Hz and 0.98 Hz).

Given the limitations of the work of Alexander et al. (1945), and the inherent difficulties of conducting field studies, O'Hanlon and McCauley (1974) systematically examined the influence of vertical frequency and acceleration levels upon motion sickness incidence using a laboratory ship motion simulator. The study exposed 306 male college students to a

variety of vertical frequency and acceleration conditions ranging between 0.083 Hz to 0.500 Hz and 0.03 g to 0.40 g. Separate groups of 20 or more subjects were subjected to a particular motion environment for a two hour period or until first emesis.

Motion sickness incidence (percent of population experiencing emesis) was found to be maximum at 0.167 Hz for any given acceleration level. Deviation from the nodal frequency led to a reduction in emesis incidence if the acceleration level was held constant. Furthermore, emesis incidence was found to increase monotonically with acceleration level when frequency was held constant. A graphic representation of the motion sickness incidence prediction model developed is presented in Figure 1.

The above study represents a significant advance over previous laboratory studies in that a much wider range of motion environments was examined with sinusoidal rather than square wave oscillations. Yet, several questions remained concerning the contributions of more complex wave forms and combinations of linear and angular accelerations.

McCauley et al., (1976) examined the influence of roll and pitch motions separately, and combined with heave motions, upon emesis incidence. Three angular frequencies (e.g., 0.115 Hz, 0.239 Hz and 0.345 Hz) were combined with three levels of angular accelerations (e.g., 5.5, 16.7 and 33.3 $/sec^2$) in a

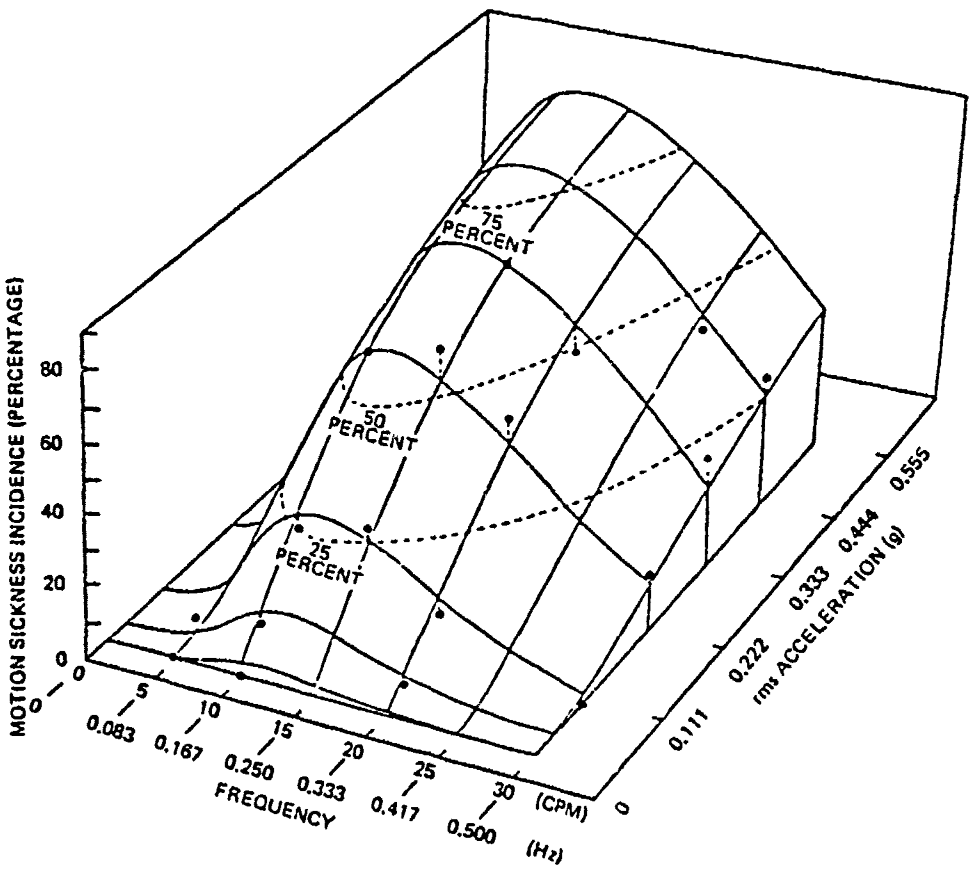

Figure 1: A model of motion sickness incidence (MSI) as a function of vertical frequency and acceleration for two-hour exposures (taken from O'Hanlon and McCauley, 1974)

partial factorial design to yield six different angular motion environments. These angular motions were superimposed upon a heaving motion of 0.11 g at 0.25 Hz with the subject's orientation in the test compartment dictating whether angular motions experienced were pitch or roll. Six pitch and heave, six roll and heave, and three "control" motions (pitch only, roll only or heave only) were examined for differences in subject motion sickness incidence. No significant differences were obtained with combined motion environments from the heave only motion environment.

The results, which reaffirmed the validity of the motion sickness incidence prediction model derived earlier (O'Hanlon and McCauley, 1974), indicate that within the linear and angular frequency and acceleration envelopes of today's vessels, only heave may be of importance in predicting motion sickness.

A preliminary experiment, conducted to evaluate the feasibility of the experimental paradigm used in this study, found both emesis incidence and motion sickness symptomatology severity to vary with the vessel's encounter direction to the primary swell (Wiker and Pepper, 1978). As the small monohull vessel steamed octogonal patterns in open seas, courses with head sea components (i.e., seas striking the bow) led to significantly higher reports of sickness than courses with

following seas (i.e., seas coming from the vessel's stern or quarters). See Figure 2.

These findings were replicated not only within each steaming day (two octagons were steamed during an eight hour period) but between days as well. Therefore fluctuations in motion sickness severity were attributed to the changing vessel motion characteristics. No relationships between vessel motion frequencies and accelerations could be drawn because no vessel motion recordings were made. However, the findings support the belief that frequency and acceleration profiles such as those provided by O'Hanlon and McCauley (1974) exist and can, upon validation, be useful in vessel design efforts to improve crew habitability and performance.

To date, however, no shipboard studies have been conducted to validate the motion sickness incidence prediction model and support the hypothesis that only vertical (vessel) motions are important in the provocation of motion sickness. Moreover, the prediction model discussed is limited to prediction of emesis incidence but subemesis levels of motion sickness may be equally or more important from a physiological, affective state, or psychomotor performance standpoint.

Vessel Motion, Motion Sickness and Antidiuretic Hormone Release

Measurement of motion sickness incidence and severity has relied in the past upon subjective information provided from

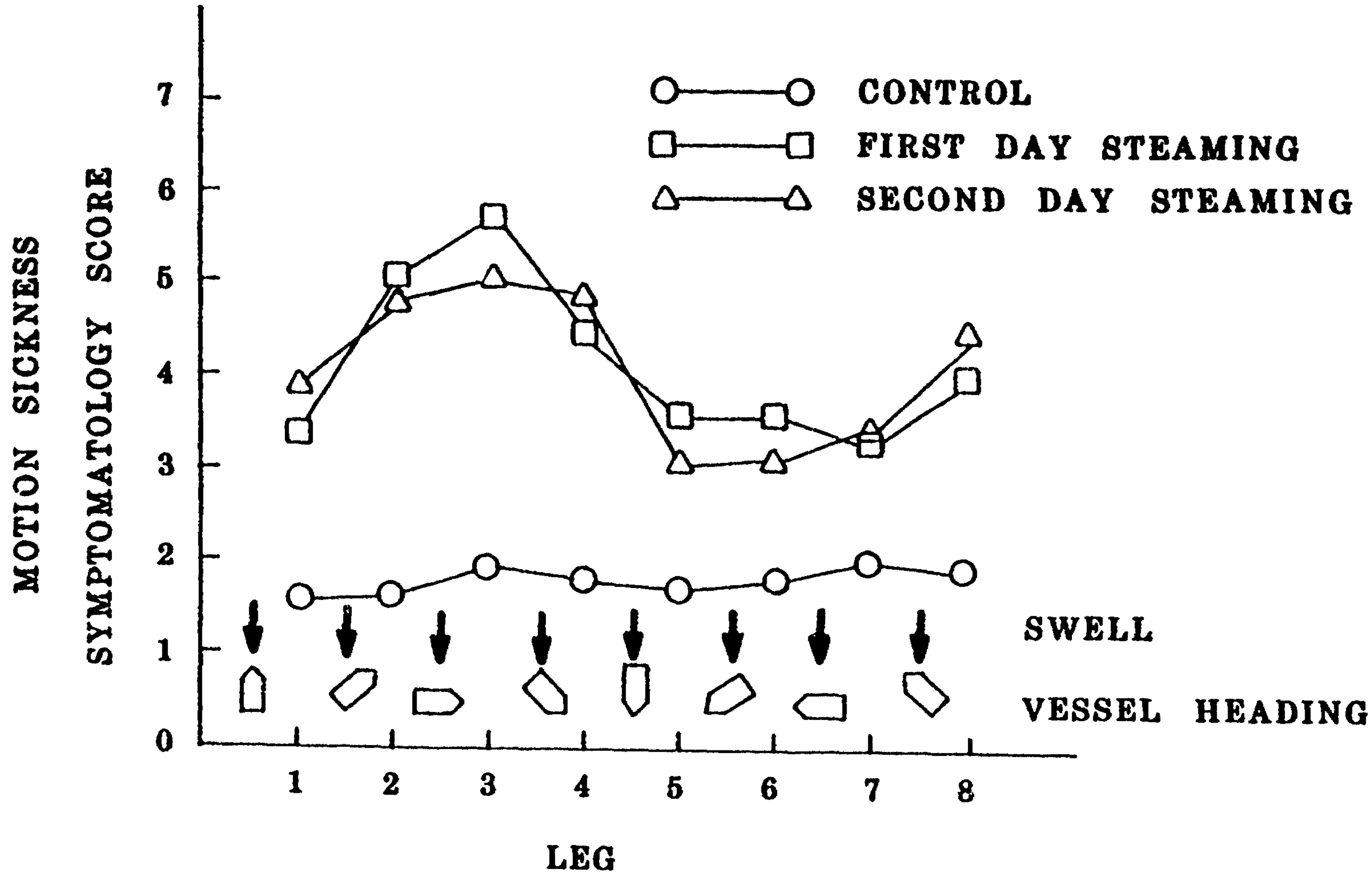

Figure 2: Motion Sickness Symptomatology Severity per Octagonal Steaming Leg (taken from Wiker and Pepper, 1978)

subjects or observers. Although reliable subjective assessment techniques are evolving, they lack the advantage of objective measures. One promising objective index is that of anti-diuretic hormone (ADH) secretion rate.

Taylor et al., (1957) investigated the effects of laboratory induced motion sickness upon urine production rate, urine specific gravity and urine chloride concentration in humans and dogs.

Total void urine samples from humans, and aliquotted samples from catheterized dogs, were collected evey 15 minutes during a two hour control period. Immediately following each collection, subjects were provided water or a diluted punch to drink until their body weight returned to the initial level. Distilled water was provided to the dogs by gavage

Following the control period subjects were exposed to either a swing or turntable apparatus to induce motion sickness. Humans exposed to the turntable experienced 30 rpms while their heads were mechanically manipulated vertically in a 36 degree arc to bring about motion sickness within a two to three minute period.

Humans and dogs were exposed to swings which produced whole body motions of 70 degrees in arc at 16 cycles per minute. Swing exposures brought on severe nausea and the urge to vomit in humans generally within six minutes while nine minute exposures for dogs produced profuse salivation.

Results showed 72% of subjects who reported severe nausea experienced a 65% or greater reduction in urine output. Furthermore, urine specific gravities and urine chloride concentrations increased with reduced urine flow associated with motion sickness. Urine chloride excretion rates remained unchanged. Of those subjects reporting little or no motion sickness, 80% experienced less than a 25% reduction in urine output from control levels.

Resulting antidiuresis was attributed to the release of antidiuretic hormone from the neurohypophysis, although hemodynamic effects from acceleration exposures might have contributed to urine production rate changes. Ancillary experiments, conducted with turntables and no subject head movements (i.e., little or no motion sickness) resulted in little reduction in urine production, thus, discounting any significant hemodynamic contributions. Moreover, the increased specific gravity and urine chloride concentrations, observed without changes in chloride excretion rates during periods of reduced urine output, indicate such results were due to renal resorption of water rather than changes in glomerular fitration rates.

Graybiel et al., (1965) while investigating the effects of long-term exposure of humans to slow rotation at 10 rpm, found significant reductions in urine production during the first two days of exposure. During the last half of the 12 day

experimental period urine production increased toward control levels while motion sickness severity declined despite considerable individual variability between the four subjects studied. Although the authors report bioassays of the urine samples indicate samples collected during periods of motion sickness contained an ADH-like substance(s) no further information was provided.

The most conclusive evidence for correlation between motion sickness and ADH release comes from the work of Eversmann, et al. (1978). Frank motion sickness, induced by rhythmic head movements made in cardinal directions aboard a rotating chair, produced on the average a twenty-one fold increase in blood ADH from presickness levels ($r = .96$, $n = 31$). Urine samples collected for 12 hours beginning two hours prior to rotation exposure were reported to be significantly lower in volume than control levels; however, no volumes were provided in their report. Twelve-hour urine samples collected, which included the motion sickness episode, showed significantly elevated specific gravities when compared to control values ($\overline{x} = 21.5\%$) while serum osmolality remained unchanged.

Hormone secretion during the rotation period leading to emesis was examined in eight subjects using blood samples taken every four minutes pre, per and post rotation. ADH release was found to be stimulated prior to emesis and in

concert with developing symptomatology severity, while rotation without head movements, consequently without motion sickness, failed to elevate ADH levels.

Results from these studies suggest the utility of direct or indirect measures of ADH release in efforts to measure objectively changes in motion sickness severity. Investigations thus far have been restricted to short-term exposures to highly provocative environments or to long-term exposures to consistent single dimension motion stimuli.

A pilot experiment conducted for this study found significant relationships between both urine output ($r = -.65$, $p < .05$) and motion sickness symptomatology reports (Wiker et al., 1979b). Significant changes were observed in both urine volumes and specific gravities from control (dockside) two-hour total void samples and samples collected at sea (see Figures 3 and 4).

No significant variations were found within steaming days in either urine output or specific gravity despite exposure to octagonal steaming patterns which led to large and consistent variations in motion sickness severity (see Figure 2).

The lack of within-day variation was attributed to the small subject population employed ($n = 6$) and the lack of statistical control of temperature and humidity changes within the testing periods.

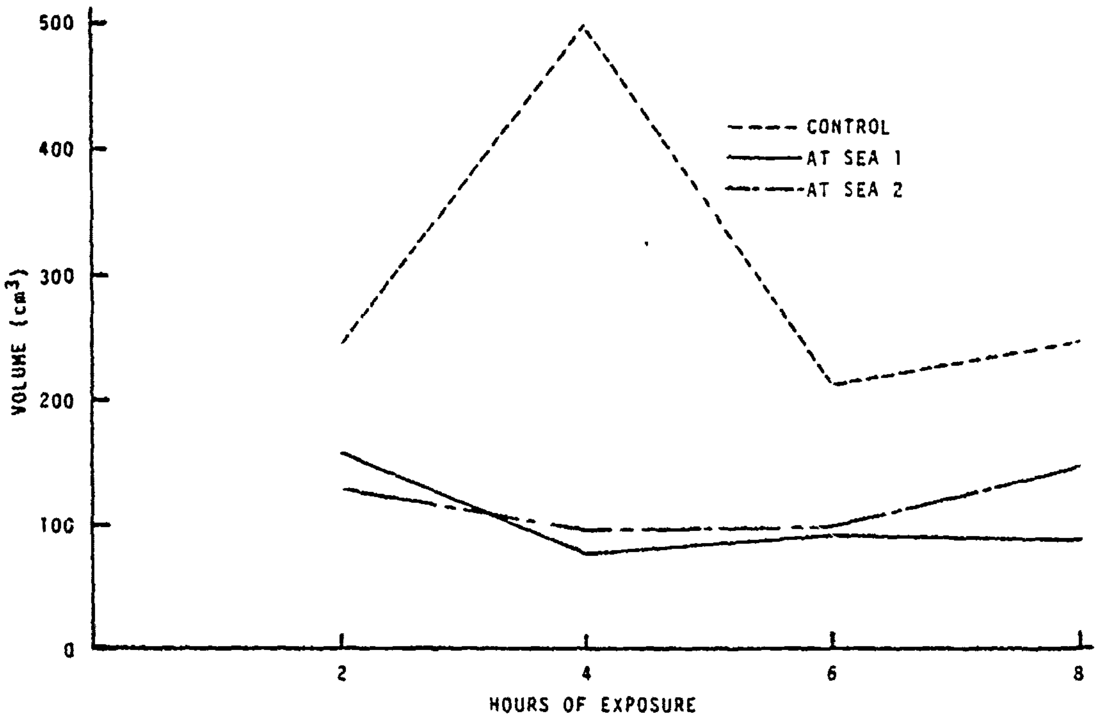

Figure 3: Mean urine output comparisons between dockside and steaming days (taken from Wiker and Pepper, 1978)

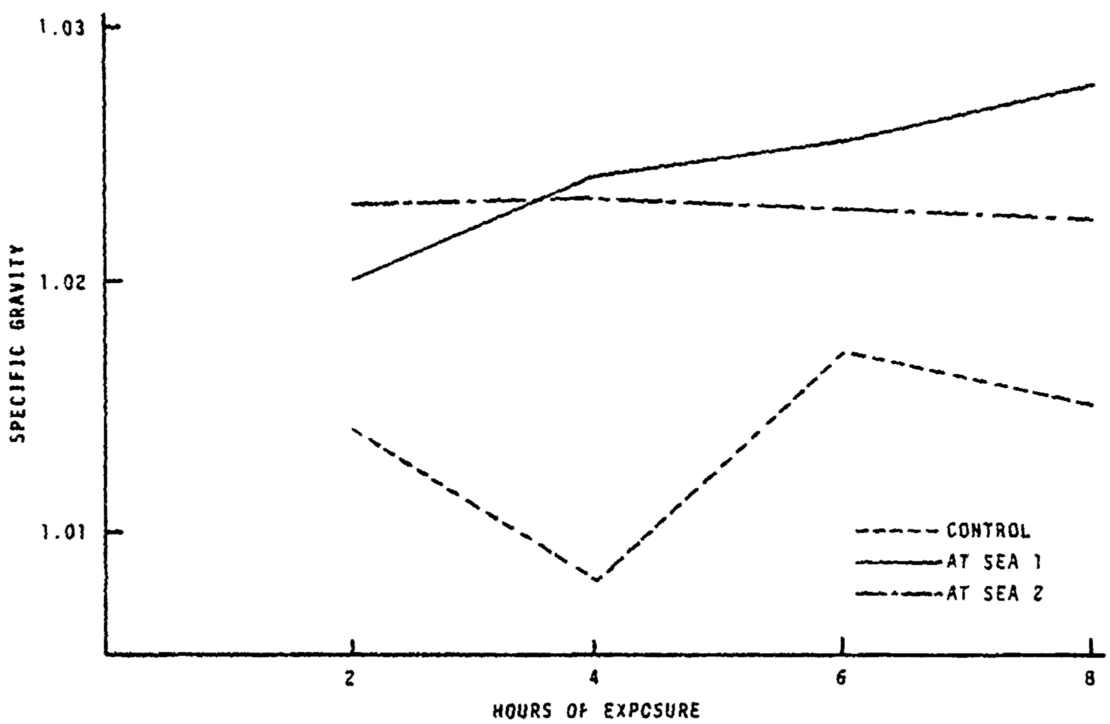

Figure 4: Mean urine specific gravity comparisons between dockside and steaming days (taken from Wiker and Pepper, 1978)

Further examinination is required to determine whether ADH release, urine output or specific gravity can be used reliably as objective measures of motion sickness severity under long-term field circumstances where complex and ever-changing motion environments result in cyclic, random or subtle changes in motion sickness severity.

Vessel Motion, Motion Sickness and the General Adaptation Syndrome

The General Adaptation Syndrome (GAS), originally described by Selye (1936) may be described as a stereotypic physiological response to noxious stimuli, independent of the nature of the stimuli, and which is most notably characterized by enhanced adrenal gland activity and hypertrophy (Cannon, 1914; Selye, 1950; Mulrow, 1972). Two widely employed measures of adrenal activity and environmental stress are catecholamine and gulcocorticord secretion rates.

Catecholamines and glucocorticoids differ in their origins, synthetic pathways, chemical structures, physiological effects, catabolism, and to some extent the stimuli responsible for their release. Catecholamines such as epinephrine, norepinephrine and dopamine are dihydroxyphenylamines which are produced in the brain, sympathetic nerve endings, and chromafin tissue sites such as the medullary region of the adrenal gland. As dopamine is primarily a

neural transmitter with very little secretion into the blood stream by the adrenal gland, the following discussion shall consider only epinephrine and norepinephrine.

Release of large amounts of epinephrine and norepinephrine from the adrenal medulla during periods of stress leads to a variety of physiological effects which may serve to maintain sustained physical activity. Elevations in catecholamine levels lead to increased cardiac output, pulmonary ventilation, blood glucose and free fatty acid concentrations, along with redistribution of the body's blood supply from nonessential areas such as the skin, mucous membranes and viscera to tissues of greater immediate survival importance (e.g., skeletal musculature and brain). Redistribution of the blood supply to skeletal muscles increases not only the amount of available metabolic substrates necessary for increased muscular activity, but serves to reduce muscular fatigue by removing metabolic waste products such as carbon dioxide and lactic acid (Axelsson, 1971; Williams, 1974; Innes and Nickerson, 1975).

To increase adequate substrate levels for muscular and central nervous system activity, catecholamines inhibit insulin secretion, promote glycogenolysis and gluconeogenesis in the liver, glycogenolysis in muscle, and stimulate the breakdown of adipose tissue to release free fatty acids for

muscle metabolism (Celander, 1954; Bueding and Bulbring, 1964; Porte and Williams 1966; Kosterlitz, 1968).

Aside from the metabolic influences discussed, elevations in circulating catecholamines increase contractility of fast twitch muscles, promote contraction of the radial muscles of the eye (dilation) to permit entry of more light and relaxation of ciliary eye muscles to increase depth of field at the expense of near-field vision. Such changes may be of importance in performance of visually dependent psychomotor tasks.

In certain cases, increased catecholamine secretion has been correlated with changes in central nervous system state. Learning behavior and mental efficiency have been reported to improve after epinephrine secretion was increased (Bovet-Nitti, 1965; Frankenhaeuser et al., 1970; Patkai, 1971a). These improvements, which were attributed to increased vascular supply to the brain and activation of the reticular formation, were significantly correlated with epinephrine secretion rates. However, other studies have reported no significant correlations between vigilance or cognitive performance and either epinephrine or norepinephrine secretion (Bloch and Brackenridge, 1972; O'Hanlon and Horvath, 1973).

Factors controlling the release of catecholamines are as varied as the physiological effects of catecholamines.

Catecholamine secretion is governed directly by sympathetic innervation of the adrenal medulla and indirectly through changes in basal synthesis rates associated with diurnal rhythms and varying concentrations of other homrones (e.g., adrenocorticotropic hormone (ACTH), follicle stimulating hormone (FSH), angiotensin II, histamine, bradykinin, serotonin and tyramine) and possibly as a result of vestibular activation or mediation (Colehour and Graybiel, 1966).

Once released into the blood, catecholamines are transported to effector organ sites where, upon stimulating cyclic AMP formation, they are destroyed by plasma or intracellular enzymes, rebound into granules within sympathetic nerves or are excreted in the feces, sweat or urine (von Euler, 1964; von Euler, 1966; Axelsson, 1971). The half-life of catecholamines in the blood is relatively short (2-3 circulation times according to Axelrod et al., 1959) and, therefore, catecholamine levels have been useful in gauging stress in environments where stressor levels change rapidly.

The amount of catecholamines excreted in the urine represents only a few percent of the amount secreted by the adrenal gland, yet measurement of free catecholamines, or their metabolites, in the urine has proven to be a reliable index of blood levels (von Euler, 1964, 1966). Urinalysis techniques offer advantage over blood sampling through greater subject acceptance, ease and safety in sample collection, and

less interference with psychomotor performance. At the same time, however, urine sampling techniques require longer time intervals between samples, thus reducing the ability to resolve short-term responses to stressors.

Normal urinary excretion values for combined levels of epinephrine and norepinephrine may range between 0-115 μg per 24 hour period with excretion rates generally highest in the early morning and lowest in late afternoon (Holvey, 1972). Excretion rates during stressful situations such as childbirth, thermal extremes, hemorrhage, immobilization, heavy exercise and strong emotional states, may double or triple in magnitude from pre-stress levels (Goodall et al., 1957; Sundin, 1958; Pekkarin et al., 1961; Levi, 1965; von Euler, 1966; Patkai, 1970; Bloch and Brankenridge, 1972; von Euler, 1972; Sultanov, 1975; Bhagat and Hornstein, 1975; Kujalova et al., 1974; Kozlowski et al., 1974; LeBlanc, 1975; Mikulaj et al., 1975; Krahenbuhl et al., 1977).

Unlike catecholamines, which are continually produced and stored for later release, glucocorticoids (steroid-ring based structures synthesized in the cortex of the adrenals) are released in proportion to their rate of synthesis. Control of synthesis appears to be largely controlled by ACTH release from the adenohypophysis.

Stressors may act upon the hypothalamus, or higher brain centers, causing an increase in the secretion of corticotropic

releasing hormone (CRF). This hormone stimulates release of ACTH from the adenohypophysis which, in turn, acts upon the adrenal cortex to stimulate production glucocorticoids, such as cortisol (McKerns, 1969; Williams, 1974).

Physiologic levels of glucocorticoid secretion act in a variety of ways to elevate or maintain blood glucose levels necessary for central nervous system activity and other glucose-dependent processes. Glucocorticoids accelerate extrahepatic protein and adipose tissue catalysis while inhibiting peripheral amino acid uptake and protein synthesis; thereby, providing necessary substrates for gluconeogenesis. Additionally, hepatic glycogen deposition is promoted and peripheral glucose utilization slowed through insulin inhibition.

Along with their effects upon carbohydrate metabolism, glucocorticoids can increase blood pressure by producing fluid shifts from cytoplasm to intravascular spaces and by prolonging the actions of catecholamines through inhibition of their degradative enzymes (Deane and Rubin, 1964).

Once released, glucocorticoids are inactivated principally in the liver, conjugated to form water soluble derivatives, and then passed out in the urine, sweat and feces (McKerns, 1969; Williams, 1974). One metabolite of cortisol found in urine, 17-hydroxycortico-steroids (17-OHCS), has been found to increase two to four times from basal levels of 3-8

mg per 24 hours under stressful conditions such as tissue injury, inflammation, hypoglycemia and electroconvulsive shock (Braun and Hechter, 1970; Kendall, 1971; Hale et al., 1970; Bloch and Brackenridge, 1972; Courtney and Marotta, 1972; Bridges and Jones, 1973; Leach et al., 1976).

Catecholamines and glucocorticoids react to a wide variety of physiological stimuli which are generally considered to be stressful. Whether the actions of these two classes of adrenal hormones are directly beneficial in defense against or adaptation to noxious stimuli requires further study. The utility of such measures as relative gauges of both physical and emotional stress, however, is widely accepted for use in within-subject experimental paradigms (von Euler, 1965a, 1965b; Mason, 1968).

Motivated by the belief that low frequency whole body acceleration and resulting motion sickness may be both physiologically and psychologically challenging, studies have been conducted to examine the relationships between catecholamine and 17-OHCS excretion rates under such conditions. Dahl et al., (1963), comparing serum 17-OHCS levels obtained during preflight and during aerobatically induced airsickness found significant increases in motion sick subjects.

Similar findings were obtained when catecholamine excretion rates were compared between labyrinthine defective (LD) and normal subjects in the same aerobatic environments.

The LD subjects, who experienced no significant motion sickness, failed to show elevations in catecholamine excretion rates while normal subjects experiencing motion sickness did (Colehour, 1965).

In a subsequent laboratory study, Colehour and Graybiel (1966) found subjection of four young naval officers to increasing coriolis stimulation over a period of six days led to nausea and increased excretion of adrenalcorticoids and catecholamines. As habituation to the motion environment occurred, the adrenal corticoid response declined to pre-rotational levels. Similar results were obtained with epinephrine, however, there was a terminal rise on the last day of experimentation which was attributed to subject anticipation.

Norepinephrine excretion, on the other hand, initially fell below control levels and gradually increased throughout the experiment. The gradual increase was attributed to elevated levels of subject physical activity associated with habituation to the nauseogenic motions.

Eversmann et al., (1978) investigating the effect of coriolis-induced motion sickness upon serum cortisol levels, found more than a two-fold increase in cortisol. The increase began 15 minutes prior to emesis and peaked approximately 30 minutes postemesis. Examining the secretion profiles of the

32 subjects studied, a high test-retest reliability was obtained ($r = .76$, $p < .01$).

Other laboratory motion generatory studies, however, have provided less supportive results. Graybiel et al., (1965) exposed four aviators to ten days of coriolis stimulation in the Pensacola Slow Rotation Room and found elevations in catecholamine and 17-OHCS excretion only during the eight and tenth days of exposure.

Jex et al., (1976) investigating primarily primarily linear accelerations in the vertical plane, similar to the vibration spectra seen aboard some surface effect ships, found no changes in serum epinephrine levels.

In the pilot experiment conducted for the present study, 17-OHCS excretion rates of the six experienced crewmen increased 123% percent ($p > .05$) from dockside group mean levels on the first day at sea and 232% ($p < .05$) during the second day at sea. At the same time, catecholamines were found to increase at sea only during the second steaming day. Steaming day 1 yielded an average group increase of 508% ($p > .05$) and steaming day 2 yielding a 197% ($p < .05$) increase. No significant changes were found within day samples nor were within day values significantly correlated to changes in octagonal steaming courses or motion sickness severity (Wiker and Pepper, 1978).

Though the evidence suggests a relationship between motion sickness incidence and stress-indicating hormone response, particularly with the adrenalcorticoids, the vast majority of studies have failed to assess systematically the influences of emotional state during motion sickness. Field studies, in which subjects were able to withdraw from experiment participation yet would still have to suffer the nausiogenic environment, have consistently shown elevations in stress hormone excretion rates. Laboratory studies in which subjects knew they could remove themselves not only from the experiment but could experience rapid elimination of motion sickness by stepping upon terra firma, have not always yielded supportive results.

As well as possible affective state differences among the studies mentioned, there are distinct differences in the motion environments themselves, experimental paradigms and, of course, subject populations which may explain the disagreements among findings.

It remains to be discerned whether elevations in stress hormones, such as catecholamines and glucocorticoids, are caused primarily by vestibular influences or by other factors such as affective state and physical demands upon the musculoskeletal system.

Vessel Motion, Motion Sickness and Heart Rate

Exposure to vessel motion may place extra demands upon the body's musculoskeletal system, increase metabolic activity, speed fatigue onset and as a result alter cardiac output.

Stressful environments have been found to cause elevations in heart rate, particularly those which are associated with significant muscular activity (Brouha and Zapp, 1967; Simonov et al., 1975) or central nervous sytem state changes (Deane, 1969; Blix et al., 1974; Fenz and Jones, 1974; Smith et al., 1974; Simonov et al., 1975).

Cardiac output may be elevated by either increasing the stroke volume or by increasing heart rate (Guyton, 1971). It appears, however, that when muscular activity is light, cardiac output requirements are met primarily by elevations in stroke volume. If workloads are increased to moderate or heavy levels, stroke volume capacity is reached, thus, forcing elevations in cardiac rate to continue meeting cardiac output demands (Brouha and Zapp, 1967).

Heart rate elevations have also been associated with particular emotional states such as anxiety or aggression (Blix 1974 Simonov et al., 1975; Bloom et al., 1976; Deane, 1969). Heart rate changes seen with shifts in affective state may, however, be tempered by performance task demands.

Cognitive or problem solving tasks, which are characterized by environmental rejection (e.g., digit-symbol, recall and Stroop Color-Word), generally show elevations in heart rate. On the other hand, tasks which require environmental acceptance (e.g., vigilance tasks) were associated with reductions in cardiac rate. Complex tasks involving mixed types of performance are associated with no significant changes (Dahl and Spence, 1971).

Examination of cardiovascular activity of subjects exposed to laboratory vessel motion simulators has generally showed modest changes. Using a swing pole motion generator to induce motion sickness, Hemingway (1945) found pulse rates to generally decline with exposure although there were large individual differences. Emesis was associated with increased pulse rate but no relationship was found between motion sickness incidence and resting blood pressure. Crampton (1955) using an elevator card for a vertical motion generator, produced similar results when sick versus nonsick group comparisons were made.

These laboratory findings indicate that very low frequency whole body motion, or motion sickness, are not likely to affect heart rate except during the period of emesis. Yet no studies have been performed aboard actual vessels where the dynamics of the environment are more complex and possibly more taxing from a musculoskeletal standpoint.

Moreover, previous studies have examined subjects who were not actively performing tasks. Changes in heart rate may be seen when the complexity of the motion environment is enhanced and subjects are faced with a sustained workload.

Vessel Motion, Motion Sickness and Sweat Rate

Sweating has been long recognized as a symptom of motion sickness and is incorporated in the majority of motion sickness severity scoring procedures discussed previously. Cold sweating is visibly progressive with the development of the motion sickness syndrome and has, therefore, been used in the past for objective measurement of motion sickness severity and susceptibility prediction (Hemingway, 1946; McClure et al., 1971).

Use of sweat rate alone as a measure of motion sickness severity is complicated by thermal and metabolic influences. McClure and Fregly (1972) examined sweat rates of eight young males subjected to coriolis-induced motion sickness under strictly controlled thermal conditions. Galvanic skin response and electrochemical moisture sensors were placed on the dorsal surface of the hand and continuous recordings were made while subjects performed head movements in a rotating chair to induce sickness to the point of stomach awareness. Experiments were repeated under a variety of thermal

conditions to examine resulting changes in the onset of an arbitrary sweat rate endpoint and its relationship to the first report of nausea.

Results showed sweat rate to be effective as an indicator of motion sickness onset as well as habituation within an individual's thermal range. If ambient temperatures were too cold, the cold sweat response was abolished altogether. On the other hand, warm environments, which induced significant thermal sweating, shrouded both the onset and degree of the cold sweat response. Within the individual's acceptable thermal range, sweat rate endpoints were encountered sooner, with a given provoking stimulus, as ambient temperatures increased. McClure and Fregly hypothesized that such changes may be a result of neural summation of both vestibular and thermal receptor input or that vestibular stimulation effectively changes the hypothalamic "set point" for thermal sweating. Regardless of the mechanism involved, results from these studies indicate that if appropriate thermal conditions are maintained, sweat rate information may be of value in objectively discriminating between motion environments which provoke only mild degrees of motion sickness.

Vessel Motion and Affective State

Exposure to stressful stimuli can bring about measurable shifts in mood (Nowlis, 1965; Spielberger, 1972). The direction, magnitude and transiency of such shifts appear to be related to the type, magnitude and duration of the stressor as well as the physiological and psychological posture of the individual.

Changes in affective state during exposures to stressful situations may have several consequences. First, mood shifts may be either advantageous or disadvantageous in the individual's attempts to deal with the stressor(s). Second, changing affective state may alter managerial or leadership effectiveness. Third, chronic or sustained negative mood shifts may yield coping behaviors which interfere with organizational goals (e.g., absenteeism, reenlistment rejection). Finally, mood shifts can lead to direct or indirect physiological changes (e.g., sleep loss, increased adrenal activity, cardiovascular changes) which in turn may affect both the short and long term health of the individual (Spielberger, 1972).

Although one would prefer to be able to make statements regarding the impact of vessel motion upon the

aforementioned concerns, assessment of mood shifts in this study was motivated by previous reports of mood shifts associated with very low frequency whole body motion exposures and their possible influences upon physiological and performance measures.

Apathy, depression, anxiety or fatigue are frequently reported either by subjects experiencing motion sickness or by clinical observers (DeWit, 1953; Clark and Graybiel, 1961; Graybiel et al., 1965; Abrams et al., 1971; Wiker and Pepper, 1978).

Abrams et al., (1971) used a mood adjective check list (MACL) developed by Nowlis (1965) to systematically evaluate the influence of simulator motion severity upon subject affective state. See Table 1.

Of the ten mood dimensions examined by Abrams et al. (1971) (social affection was not examined) only reports of reduced vigor and increased fatigue showed any changes upon motion exposure and resulting motion sickness. Such changes were not, however, systematic in nature and proved to be more sensitive to time of day influences than to sea state level.

The same MACL was employed in a pilot study in which six experienced Coast Guardsmen were subjected to two consecutive steaming days aboard a 95' Coast Guard Patrol Boat in sea state two conditions (Wiker and Pepper, 1978). Checklists, completed each half hour during the eight hour exposure

TABLE 1--Affective Dimensions and Their Associated Adjectives.

Aggression	Fatigue	Vigor
Angry	Drowsy	Active
Defiant	Sluggish	Energetic
Rebellious	Tired	
Anxiety	**Sadness**	
Clutched up	Regretful	
Fearful	Sad	
Jittery	Sorry	
Concentration	**Skepticism**	
Concentrating	Dubious	
Engaged in Thought	Skeptical	
Intent	Suspicious	
Egotism	**Social Affection**	
Boastful	Affectionate	
Egotistic	Kindly	
Self-Centered	Warm Hearted	
Elation	**Surgency**	
Elated	Carefree	
Overjoyed	Playful	
Pleased	Witty	

periods, showed only one mood dimension, fatigue, to change significantly between dockside to steaming day. Subject concentration and skepticism reports showed significant and consistent within day variations associated with octagonal steaming patterns.

Correlational analyses of MACL responses showed significant associations between motion sickness symptomatology severity scores and mood dimensions of fatigue ($r = .83$; $p < .01$) and concentration ($r = -.50$; $p < .01$). Whether additional changes will be found when larger numbers of subjects and more extensive tests are conducted at sea remains to be seen.

Vessel Motion and Human Performance

Crew performance at sea may be perturbed as a result of biodynamic interference, increased fatigue and possibly motion sickness associated with the motion environment. In the past, performance decrements have been largely disputed by investigators using laboratory based motion generators. However, more recent studies under both real world and laboratory conditions indicate performance is vulnerable to ship motion or motion sickness.

Early studies using purely vertical motion generators found no significant post exposure decrements in performance tasks such as running through sand, running a 60-yard dash, dart throwing, speed and accuracy rifle shooting, code substitution, and mirror drawing following a twenty minute exposure period. Only a tracking task, the Mashburn Complex Coordinator, showed a significant post exposure decrement (Alexander et al., 1945; Alexander et al., 1947; Johnson and Wendt, 1964).

Similar findings were obtained in Slow Rotation Room (SRR) studies in which subjects were exposed to rotational environments between 1.7 and 10 rpms for various numbers of days (Clark and Graybiel, 1961; Guedry, et al., 1964;

Graybiel, et al., 1965). Experimental results showed that motion sickness, except during the act of emesis, failed to degrade performance in combination lock opening, arithmetic computation, dial setting, card sorting, dart throwing, ball tossing and Whipple Steadiness Test scores. Nonsignificant fluctuations in these scores were attributed to shifts in subject motivation levels. However, grip strength, tracking capability and time estimation performance did suffer decrements when four aviators were subjected to 10 rpms for twelve days in the SRR (Graybiel et al., 1965).

Abrams et al. (1971), using a vertical motion generator, examined the effects of exposure to various sea states upon tasks performed by experienced sailors. No performance differences were found between sea states (SS) 0, 3, 4, 4.5, and 5 in tasks such as target classification, turn count tasks, sonar target detection, Doppler Tests, Revised Minnesota Paper Formboard Tests, memory and reading comprehension exams. The authors reported, however, that learning effects were significant and may have shrouded possible performance decrements.

More recently, Jex et al. (1976), experimenting with a three degree of freedom motion generator, in an effort to establish design criteria for a two thousand ton surface effect ship, found exposure to motions between 0.2-2.0 Hz at 0.5-1.0 g led to interference in motor tasks

(e.g., navigation plotting, lock opening, writing and critical tracking capability). Subjects reported, via postexperiment questionnaires, that such decrements were due primarily to biodynamic interference rather than to indirect effects of the motion environments such as motion sickness.

Simulated surface effect ship motions and associated motion sickness produced no significant decrements in sensorimotor tasks such as auditory vigilance, short term memory or critical flicker fusion rates. These results concurred with an earlier investigation (Clement and Shanahan, 1974).

In contrast to the majority of laboratory findings, field studies which have assessed the effects of more complex whole body motions upon performance, have shown that performance can be perturbed by motion environments leading to motion sickness. Brand et al. (1967), examined the effects of an antimotion sickness preparation upon the computational ability of men exposed to motions aboard a life raft. Life raft motions and resulting motion sickness led to significant reductions in computational ability when compared to preexposure levels. Moreover. subjects provided with placebos completed significantly fewer additions than did subjects using antimotion sickness drugs.

A study conducted by Sapov and Kuleshov (1975) analyzed the effects of long term exposure of a ship's crew to actual ship motion. The influence of vessel motion upon

three different categories of performance was evaluated. The performance variables were categorized as physical efficiency, mental efficiency or professional efficiency.

Physical efficiency was measured through the use of aerobic and static muscle strength tests while mental efficiency was evaluated through the use of mental arithmetic tasks, Landolts' Ring test, rearrangement of numbers encountered in tangled lines, tracking tasks and simple visual reaction times. Professional efficiency was measured by comparing the speed of performance on tasks associated with professional specialities under experimental conditions with that of established "norms".

Data were collected during the six-week study under the following sequence: one week steaming under calm sea conditions within a sheltered bay; a second week of steaming outside the bay on the open seas; and a final three weeks at sea immediately following the second stage. Significant decrements were reported in physical, mental and professional performance during the third stage. The improvements, however, generally remained below control levels established in calm waters.

Physicial efficiency continued to decline through stages two and three. This continual reduction was attributed to the chronic stress and fatigue associated with postural demands made by the constant rolling action of the ship.

It is interesting that the primary reduction in mental and professional efficiency was attributed not to a reduction in the rate of task completion, or quantity of work, but rather to large reductions in the quality of performance (i.e., increased error rates).

Another real world study, conducted to evaluate the feasibility of the experimental paradigm and sensitivity of measures used in this study, examined a variety of performance measures under actual steaming conditions (Wiker and Pepper, 1978). Performance tests such as navigation plotting, grammatical reasoning, visual search, complex counting, critical tracking, code substitution and Spoke Test were administered to six experienced crewmen aboard a 95' WPB Coast Guard Patrol Boat while dockside and under steaming conditions in sea state 2.

Results showed significant decrements in navigation plotting accuracy and visual search performance in a letter search task despite noticeable learning effects and small sample size. No significant decrements were found in grammatical reasoning, complex counting, critical tracking, code substitution or Spoke Test performance; however, with the exception of grammatical reasoning all tasks studied exhibited learning effects.

Navigation plotting accuracy scores were found to be significantly correlated with steaming encounter direction to the sea's primary swell. Courses producing head or bow seas, which also led to the greatest motion sickness severity, yielded the poorest navigation plotting accuracy scores. Whether such decrements were due to biodynamic interference, motion sickness, or a combination of both, could not be determined because no objective vessel motion records were made.

In summary, human performance appears, to some extent, to be vulnerable to either the direct or indirect effects of vessel motion. Given the paucity of studies examining the effects of whole body motion below 1 Hz, no general statements are permissible concerning the types of performance which may be expected to suffer aboard ships or the characteristics of the motion environments responsible for performance decrements.

The apparent disagreement between some laboratory and field study findings in the area of human performance may not be genuine. Although the severity of motions studied in the laboratory was probably greater than the more complex real world environme , no data exist from ship motion studies to enable objective comparisons. Furthermore, though a variety of performance tasks were examined under both

testing strategies, few tasks were similar enough to make critical comparisons.

Clearly, additional research is necessary under very low frequency high amplitude motion environments to determine the magnitude and scope of motion sickness and acceleration influences upon human performance.

Performance Test Battery

In the present study, a battery of psychological tests was administered to assess the effects of motion on such psychological processes as short-term memory, pattern recognition, signal detection and processing and mathematical reasoning. These are objective measures which are related to successful performance in many important shipboard jobs, especially with regard to watch standing, surveillance, and search and rescue. Six tasks were selected which were considered both relevant to the performance areas of concern and of sufficient reliability, validity, and sensitivity to detect changes in performance produced by stress. The candidate measures ranged in character from simple to complex, from operational to abstract and from machine to subject-paced.

The battery of tasks was selected or constructed to meet the following criteria: a) the tasks were to measure a variety of cognitive and psychomotor skills; b) possess operational relevance (i.e., had similar components to those occupational duties normally performed aboard ship; c) possess sufficiently good statistical reliability so that repeated

testing was possible; d) and possess sufficient sensitivity to stress induced performance decrements.

Tasks were selected based upon results obtained from a pilot study (Wiker and Pepper, 1978) and ongoing work by Kennedy and Bittner (1978). The six tasks employed in this study were:

a) Navigation Plotting Task

b) Critical Tracking Task

c) Spoke Test

d) Complex Counting Task

e) Code Substitution Task

f) Time Estimation Task

Navigation Plotting Task

The primary requirement of any ship, military or nonmilitary, is to navigate safely and accurately from one position to another. To accomplish this goal requires the operation of electronic and mechanical navigation equipment (e.g., loran. radar, sextant, etc.), mathematical reasoning and operational manipulation of plotting equipment such as triangles and dividers in the attainment of geometric and trigonometric solutions to navigational problems.

Navigation and position plotting performance is not only important in the satisfaction of strategic operational mission, but it provides information to bridge personnel

regarding relative movement of other vessels or navigational hazards which is necessary for collision avoidance, target pursuit and interception or escape from pursuers. Furthermore, such skills enable utilization of environmental information (e.g., current set and drift, true wind velocity) required for safe and effective ship handling.

To assess the effects of vessel motion upon these skills, a navigational plotting task was developed using standard plotting equipment and procedures typically employed aboard all Coast Guard and Navy ships. The task was subject-paced and required subjects to plot the relative movement of a target vessel using a pair of triangles, a compass and a standard maneuvering board. In addition to plotting the relative movement, subjects were required to employ arithmetic and geometric reasoning, as well as nomogram interpretation, to compute the relative course, speed and closest point of approach of successive target vessel movements.

Although the task does not involve the more complex types of plotting problems, it does employ all of the basic skills required to solve more advanced problems. The task was easily mastered with practice, yet it involved sufficient complexity to be considered demanding.

The navigational plotting task combines a variety of perceptual cognitive and motor components including numerical

computation, spatial reasoning and dexterity in a highly relevant operational task.

Critical Tracking Task

With the need for accurate and timely navigation, nearly every aspect of shipboard performance requires some form of manual operation of a control system (e.g., navigation, gunnery, communications, engineering, etc.). Degradation of performance in any of these areas can have a significant negative impact on overall shipboard performance.

To assess such performance, it is useful to consider the human operator as a biological servo-mechanism which receives input from the sensory system, integrates the sensory information within the central nervous system and produces an output in the form of a motor response. Reevaluations of the output accuracy by the operator are made in a consecutive manner. However, due to the delay in time between the input and output processes, this servo-mechanism (operator) is considered to be intermittent or discontinuous in nature. Tracking performance, or time on target, is therefore dependent upon the dynamics of the target as well as the functional integrity of the operator's sensory systems, central processing capability, and neuromuscular capacities to provide an accurate motor response. Tracking

performance is frequently employed as a measure of the human operator's transfer function, or effective time delay between the incoming stimulus and the outgoing response (Rose, 1974).

If the dynamics of the target can be systematically controlled, it is possible to evaluate the effects of various environments upon the operator's effective time delay. In addition to producing direct biodynamic interference in the operator's motor response characteristics, ship motions also may distort visual sensory systems and higher nervous center processing which could lead to decrements in tracking capability via lengthening of the operator's effective time delay.

Many forms of tracking exist for use in such evaluations (e.g., pursuit, compensatory, subcritical, critical, etc.). The critical tracking task possesses several advantages over the other forms for this particular study. First, the subject is required to compensate for, or null out, an unseen evasive target whose dynamics systematically exceed his tracking capabilities in a very short period of time. This allows several trials within a few minutes. Second, the fact that the target is unseen, with only the error between the target and the subject's pointer displayed, reduces the ability of the subject to anticipate the target's movement, making the task more difficult. Finally, the critical tracking, or critical instability score provides information concerning changes in the operator's transfer function as well

as the dynamic limits of control operation in the form of an oscillation bandwidth limit for the particular subject and the conditions existing during his performance.

Spoke Test

Linked with the importance of target recognition is the ability of personel to make accurate and timely judgments concerning the dynamics of a target. Spatial judgments are associated with functions located in, or strongly mediated by, the right cerebral hemisphere of the brain. Numerous investigations have been made concerning not only types of performance specific to a particular cerebral hemisphere but the degree of performance impairment associated with specific degrees of organic brain damage to each hemisphere.

One such study was performed using an Army intelligence test, the Trail Making Test (Manual: Army Individual Tests, War Dept.; The Adjutant General's Office, 1944), to investigate the degree of organic brain damage in neurological patients (Reitan, 1955). Results showed that not only did successful performance hinge upon subject alertness and concentrated attention, but that scores with numeric forms of the test were highly correlated with damage to the right hemisphere; the lower the score the greater the extent of the damage (Reitan, 1958; Fitzhugh, Fitzhugh and Reitan, 1961).

The Trail Making Tests was later modified to include a motor component to distinguish between visual and proprioceptive as well as cerebral contributions to the overall quality of performance (Graybiel et al., 1965); the modified version of the test was renamed the Spoke Test.

The Spoke Test was included in the performance test battery because it involves several aspects of speeded cognitive processing such as visual search, counting/storage, and directional movement initiation. In addition, it is easily administered and equipment requirements are minimal (e.g., pencil, paper, and stopwatch).

The Spoke Test requires subjects to move a pencil from a central circle to a peripheral circle which contains a number, then return again to the central circle. This process is repeated for each of the thirty-two equidistant concentric peripheral circles in numerical order. When the numbers in the peripheral circles are randomly ordered, the subject must visually search the periphery and judge whether a given number is greater or lesser than the number sought. By subtracting the time required to complete the simple tapping task from that of the more complex search task, it is possible to obtain an indication of the processing time required by the right hemisphere to successfully complete the usual search and numeric comparisons. The difference score is less contaminated with variations in proprioception and

neuromuscular capabilities between subjects and, therefore, is thought to be a more reliable indicant of disruption in central processing of spatial forms of information.

If vessel motion or motion sickness produces significant increases in the difference scores obtained with the Spoke Test, then spatial judgment capabilities of shipboard personnel could be expected to decline.

If the simple movement, or tapping task, shows significant time increases, then the ability of personnel to effectively manipulate multiple control panels in engineering control rooms, on radio or navigation equipment, etc., would also be expected to degrade under the influence of vessel motion.

Complex Counting Task

Aboard ship, long periods of sustained attention and utilization of short term memory are generally required of radarmen, sonarmen, lookouts and radiomen. To evaluate changes in these parameters under steaming conditions, an auditory complex counting task was selected (Kennedy and and Bruns, 1975).

The task was originally conceived from observations of the varying abilities of technicians in a nephrology laboratory to monitor and count the number of drips produced from

various numbers of kidneys. Later this complex, or multiple, mental counting task was adapted to a three light flashing display for investigations of sustained attention in high noise environments; however, the maintenance of such performance was strongly associated with an increase in physiological costs.

In a comparison between visual and auditory forms of the test, Kennedy (1971) determined that the auditory form was the most difficult. The auditory version was subsequently employed in an evaluation of three different aircraft penetrating a hurricane (Kennedy et al., 1972). Error percentages were found to be related to the degree of turbulence encountered; the greater the turbulence the larger the error rate.

The complex counting task is demanding even under ideal conditions and rarely produces error free performance when two or more tones (channels) are monitored (Kennedy et al., 1975).

A reduction in the ability to sustain attention or to utilize short term memory would lead to significant errors in the mental monitoring of the quasi-randomly presented tones. If vessel motion directly or indirectly distu s these processes, then shipboard tasks which rely heavily upon such cognitive processes would be expected to degrade.

Code Substitution Task

Code substitution is a paper-pencil test developed in the early 1900's to select clerical workers and office personnel in industry. It currently enjoys widespread use, with some version employed in nearly every aptitude or intelligence test developed.

The form employed in the present study is an adaptation of the Otis (1939) digit to letter substitution task. Wechsler (1939) employed this task in WISC because he felt that it tapped elements of perceptual-speed and accuracy, an important dimension discovered in his prior factor-analytic work of human abilities.

The code substitution test was selected because of its historic use, face-validity, and the need to employ a test which is based upon perceptual-motor abilities. Additionally, it has similarities to several jobs assigned to shipboard personnel, i.e., radio room coding and decoding of messages and signalling.

Time Estimation Test

Accurate perception of the rate of passage of time is an important aspect of many tasks performed in the operational environment. Skilled performance in jobs that require judgments of velocity and motion, such as collision avoidance

and target tracking, may be dependent on accurate time estimation. Several researchers have suggested that the perception of velocity and motion may be related to one's subjective experience of time (Woodrow, 1960; Guay and Hall, 1977).

Considerable individual differences have been found among subjects in time estimation research, and, therefore, a time estimation test was a logical candidate for inclusion in the performance test battery.

Experiments on time estimation have been plentiful in the past 40 years, often addressing theoretical questions such as whether some internal, biological clock is the basis for time experience (Doob, 1971; Fraser and Lawrence, 1975). Time estimation tests have been used to determine the effects of a larger number of variables, including physiological, developmental, personality, pharmacological, environmental, and procedural variables (see Guay and Hall, 1977; Zelkind and Sprug, 1974, for bibliographies). The effects of whole body motion (vibration, rotation, sea motion) on time estimation, however, have received little research attention beyond the single study conducted in a slow rotation room. Graybiel et al. (1965) found increased error in time estimation during rotation at 10 rpm.

METHODS AND APPARATUS

Subjects

Eighteen Coast Guardsmen were selected from volunteers obtained from the existing crew aboard the High Endurance Cutter MELLON employed in the study. Selection for participation was based upon responses provided on a preselection questionnaire and learning rate of performance tasks during the training period (see Appendix A).

Subjects selected were male Coast Guardsmen who claimed and appeared to be in good health. Each subject reported a history of average susceptibility to motion sickness and a normal concern with shipboard performance, school exams and participation in sporting activities. No subjects smoked or had a habit of drinking alcohol heavily. Summary statistics of physical and shipboard experience characteristics of the subject population who successfully completed the experiment are provided in Table 2 below. (One subject voluntarily withdrew from the study after two hours of exposure to motions and motion sickness aboard the WPB).

Subject participation was voluntary and on an informed consent basis (see Appendix B). No rewards were provided to

subjects, with the possible exception that regular duty was suspended during the period of testing, and a 96 hour liberty authorization was provided to compensation for curtailed liberty during the week or experimentation.

Table 2--Subject Physical and Shipboard Experience Characteristics

	Age (yrs)	Height (cm)	Weight (kg)	Recent Shipboard Experience (mos)
$\overline{X} \pm SD$	22.1 ± 5.2	179.1 ± 6.3	74.8 ± 7.1	10.4 ± 6.4
Range	17 - 28	167.6-195.5	63.6 - 84.0	0.5 - 18

Apparatus

Data collection was conducted within similar ship's compartments located amidships and below deck aboard three different classes of vessel; a 378' WHEC Coast Guard High Endurance Cutter, a 95' Coast Guard Patrol Boat and an 89' SSP Navy Semi-Submersible Platform SWATH vessel. The testing

compartments lacked external as well as internal visual geocentric cues.

Figure 5 shows the test vessels. Table 3 provides the general descriptive characteristics of the test vessels.

Each vessel was instrumented to record test compartment translational and vessel center of gravity angular and heave motions.[1] The vessel center of gravity was located within

Table 3--General Descriptive Characteristics of Test Vessels

Vessel Descriptive Characteristics	SSP	WPB	WHEC
Length	89'	95'	378'
Beam	47'	19.9'	42'
Draft	15.5'	6.0'	20'
Displacement (tons)	217	100	3,000
Hull type	SWATH	MONO	MONO
Design speed (knots)	15-18	12-15	25-30
Crew	10	17	140

[1]Sway surge and yaw responses were not obtained from the accelerometer records.

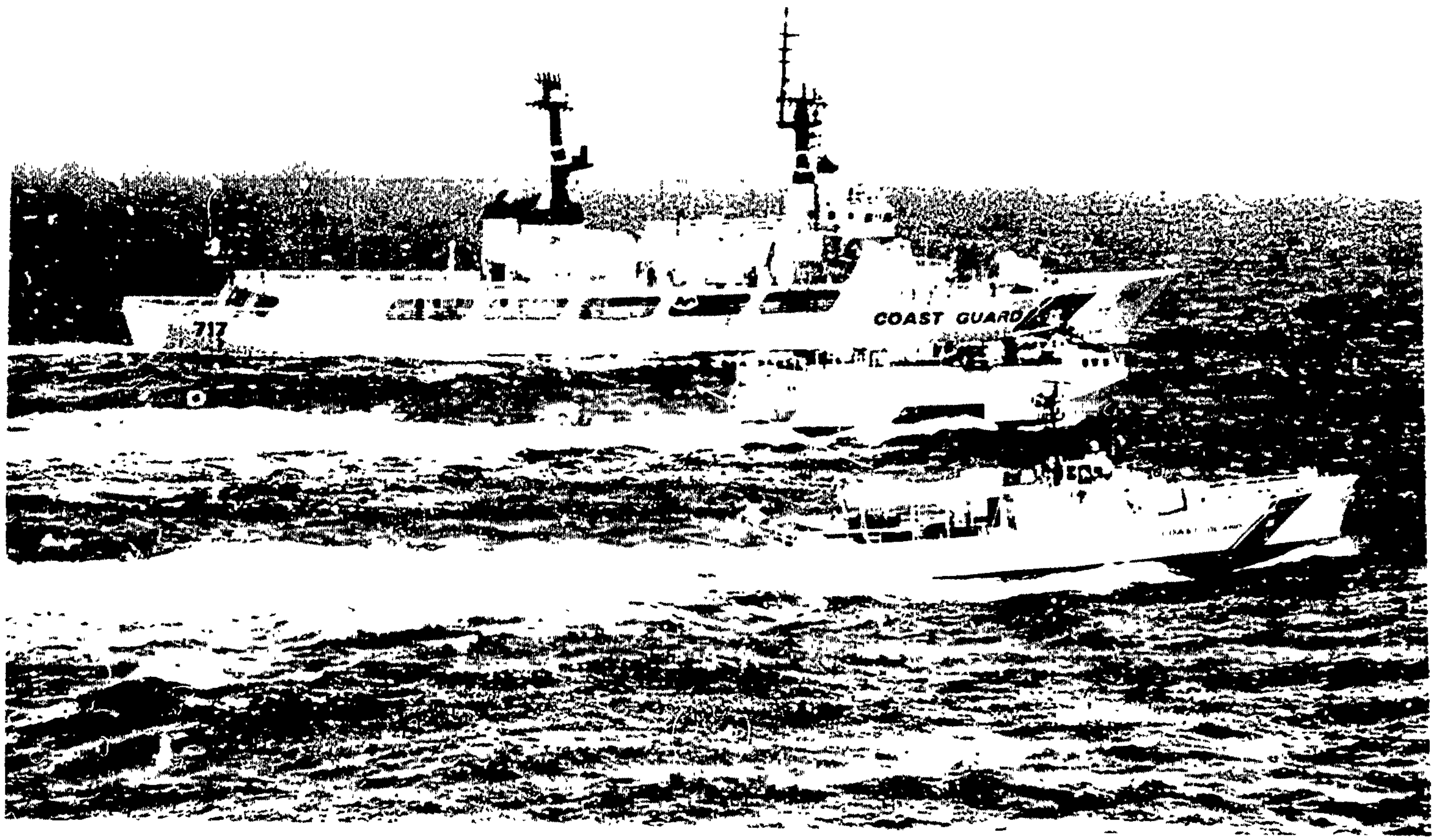

FIGURE 5-- 95' WPB Coast Guard Patrol Boat, 89' SSP Navy Semi-Submersible Platform and 378' WHEC Coast Guard High Endurance Cutter steaming respectively

five to ten feet from the test compartment. Detailed specifications of accelerometer placement, calibration signal conditioning, digitilization of taped analog responses, analysis procedures and results are provided elsewhere (Woolaver and Peters, 1980).

Sea state recordings were made from a telemetrized waverider buoy placed within the octagonal steaming pattern. Data recording and analysis procedures are provided by Woolaver and Peters (1980).

Vessel testing compartment temperatures and relative humidities were measured using a Mason's form hygrometer. Sound decibel level recordings were made in the test compartments while the vessels were underway using a General Radio Company Octave-Band Analyzer.

Procedures

Candidate subjects were trained on all performance tasks and familiarized with physiological sampling equipment and procedures for a period of one week prior to experimentation. Performance tasks were scored during this period and results used in the final selection of test subjects; thus, subjects were matched as closely as possible regarding reported motion sickness susceptibility, physical characteristics, educational level and task performance capability.

Data were collected for six consecutive days upon completion of subject training. The first two days of data collection were dockside, the next three at sea and the last day was spent dockside for the last control day. During the days at sea the vessels left port at 0700 each morning, steaming in formation to a position in deep water off the coast of Oahu, Hawaii, where at 0800 steaming of octagonal patterms was begun around a wave measurement buoy. The vessels steamed in formation at approximately seven knots initially into the primary swell thereafter 45 degree clockwise turns were made every 30 minutes.[2] AT 1600 steaming patterns were terminated and the vessels returned to port together. During dockside testing days data collection was initiated at 0800 and terminated at 1600.

Subjects, grouped into two-man teams to facilitate performance testing, were randomly assigned to vessels on a daily basis such that each team was exposed to a dockside (control) and at-sea day aboard each of the vessels.

While performing tasks in a synthetic work cycle, described in Figure 6, subject electrocardiogram (ECG) records were made continuously using Beckman standard biopotential

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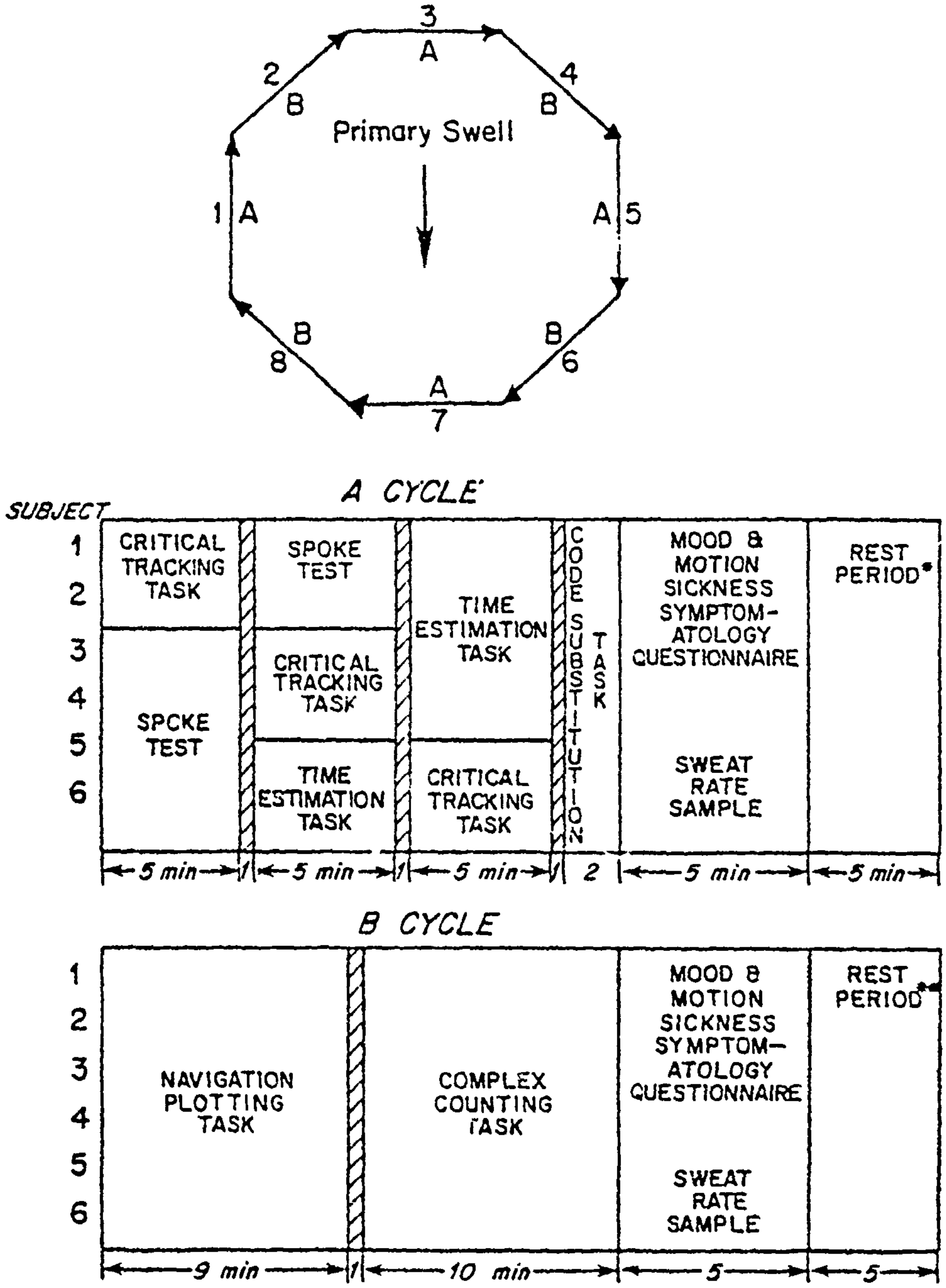
[2]Due to an engineering problem aboard the WHEC on the first day at sea, octagonal steaming patterns were not initiated until 0900 and two counterclockwise turns were made during the last half of the day to place the vessels closer to port at 1600. No such perturbations occurred during the next two steaming days.



*Subjects drank 240 ml of water or highly diluted punch

**Subjects drank 240 ml of water or highly diluted punch and provided total void urine specimens at 1000, 1200, 1400, and 1600 each day

***During steaming days vessels commenced turns during subject rest periods and were steadied up on the new course before the next cycle began

Figure 6--Data collection paradigm

electrodes following a three-lead procedure described by Goldman, 1975.

Sweat rates were sampled every 30 minutes as shown in Figure 6 using preweighed sealed absorbent fiber pads placed upon the subjects' foreheads under athletic sweat bands. After a three-minute interval, the pads and sweat bands were removed, the pads returned to their airtight containers, and reweighed at a later time to determine the volume of sweat absorbed per unit area and time.

Total void urine specimens were collected every two hours during data collection periods after discarding the morning's urine just prior to 0800. Each specimen was collected in a separate twenty-four urine specimen container, acidified with 6 ml of 6N HCl and stored in ice chests for analysis upon completion of testing each day.

Urine specimen volume, specific gravity, total catecholamine and 17-OHCS levels were determined for individual two-hour samples. Volumes were measured to the nearest milliliter using a graduated cylinder while specific gravities were determined with a clinical hydrometer. Total catecholamine levels were radioenzymatically assayed to the nearest tenth of a microgram using a modified Passon and Peuler (1973) technique. Levels of 17-OHCS in the urine were colormetrically determined to the nearest tenth of a milligram using the Porter-Silber (1950) method.

All subjects shared the same diet in which no fluids or solid foods containing caffeine or alcohol were permitted. Restriction of stimulants and alcohol was enforced 48 hours prior to data collection. The morning meal was completed one and a half hours before data collection and food was provided to subjects during testing on demand during their five minute breaks throughout the day. To insure adequate hydration and urine production all subjects drank 240 ml of water, or a highly diluted punch, every 30 minutes.

Motion sickness symptomatology and affective state were sampled after the first 20 minutes of each 30 minute period using a combined mood adjective checklist and motion sickness symptomatology questionnaire employed by Abrams et al., 1971. Mood adjective checklist responses were scaled and scored according to Nowlis and Nowlis (1956) while motion sickness symptomatology severity was scored according to Wiker et al., (1979a).

The performance task battery, consisting of six separate tasks (e.g. navigation plotting, code substitution, complex counting, critical tracking, Spoke Test and time estimation), was administered in a synthetic work cycle described in figure 6.

The navigation plotting task was an operationally based task of nine minutes in duration. Subjects were provided a test sheet containing a series of printed relative

position reports of a "target vessel." From the position reports subjects progressively plotted the movement of the target vessel using a pair of forty-five degree triangles, a compass and a standard maneuvering board (H.O. 2655-20).

Relative course, speed, and closest point of approach of the target vessel were plotted, measured, computed and recorded on the test stimulus sheet in appropriate boxes. Subjects were instructed to complete accurately as many problems as possible. Results were scored for total number completed and total number correct.

The complex counting task required subjects to listen to three different tones (100, 900 and 1800 Hz) which were presented in a quasi-random fashion for a ten minute period via a cassette tape recorder (Kennedy and Bittner, 1978). Each subject was instructed to listen to and mentally keep track of the number of occurrences of each tone. Upon reaching a count of four for any one of the three tones, the subject noted the event by pressing an appropriately coded button which transferred the event onto FM magnetic tape for later analysis. Upon pressing the button the subject reset his "mental count" for that particular tone and continued the procedure until told to stop.

Time intervals between button presses served as the scoring measure and the percent of correctly counted quartets of the lowest tone served in data analysis. The highest

tone was presented in an irregular manner which gave the appearance of randomness in tone presentations; however, the irregularity of the 1800 Hz intertone time intervals made its scoring impractical for this study.

Critical tracking task performance was investigated using a Systems Technology Inc. Mk-8A Critical Task Tester. Each subject was required to monitor and track a needle within the center of a meter type display. To accomplish this task, compensatory corrections against random needle movements were made via a freely turning control knob located beneath the meter display. Eventually, as the needle was made increasingly unstable, the limit of the subject to effectively control or nullify the needle movement was reached and the needle disappeared, ending the trial. The resultant score was displayed digitally indicating the critical tracking limit, or oscillation bandwidth (λc), at which the subject could no longer effectively track. Five trials were completed during each testing period. The median score was employed for analysis to minimize spurious biodynamic interference contributed by the jarring and pitching of the vessel at sea.

It should be noted that subjects were encouraged to take measures necessary to reduce biodynamic interference upon their tracking performance.

Code substitution tests were administered to subjects for a period of two minutes during each hour as depicted in figure 6 and as described by Wiker and Pepper (1978). During the allotted time, subjects substituted a numeric array for an alpha array using a coding matrix provided at the top of the stimulus sheet. Scores were based only upon the total number of items coded because error rates had been found negligible in a pilot study.

The Spoke Test consisted of a stimulus sheet on which a circle 24 cm in diameter was surrounded by a series of similar circles which were equidistant from the center and evenly distributed along the periphery. Thirty-two numbers, 1-32, were randomly located in each of the peripheral circles. Upon the command to start, subjects were instructed to move a pencil point from the center circle to that peripheral circle containing the number "1" and return to the center circle. This process was repeated in numerical order as quickly as possible until the subject had located and marked all 32 numbers. Upon completion of this experimental task the subject notified the experimenter, who indicated the time for completion, and logged it on the stimulus sheet.

Upon completion of the "experimental" run, a "control" run was timed in which subjects moved their pencil points from the center circle to each successive peripheral circle and back again repeatedly and in a clockwise manner as quickly as possible until all 32 circles had been tapped.

Three performance scores were obtained; Spoke experimental score (time to completion), Spoke control score (time to completion) and Spoke difference score, derived by subtracting the control score from the experimental score. The Spoke Test difference score was intended by Kennedy et al., (1979), to provide the best index of visual search time, by subtracting the limiting response time factor of motor control which is purportedly measured by the Spoke control score.

The time estimation test used in the present study was based on the method of production. A list of time intervals to be produced, ranging from 2 to 12 seconds, was provided on a test sheet. Subjects attempted to produce a given time interval by pressing a key. The key presses were automatically time coded and recorded on magnetic tape for later analysis. The subjects were allowed to count subvocally. No feedback information was given to subjects about the accuracy of their estimates.

A single administration of the time estimation test included a total of 40 trials, randomly ordered, consisting of five sets of the following eight time intervals: 2, 3, 5, 6, 8, 9, 11 and 12 seconds. The test was administered every half hour, as described in Figure 6.

Scoring of the time estimation test was done by comparing the actual duration of the subject's estimate with the

desired time interval. Due to problems in retrieving and decoding the data from the mag tape recordings, only the 12 second interval was used in analyses.

Performance test materials were appropriately randomized to eliminate unwarranted learning and other sequence effects. They were administered during a synthetic work cycle each hour.

Upon completion of testing subjects were provided post-experimental debriefing questionnaires (See Appendix C).

RESULTS

Before presenting the results, the reader should be aware of the perturbations experienced in the experimental paradigm. An engine failure aboard the WHEC delayed the initiation of steaming octagons by one hour and forced a three-knot reduction in steaming speed from the planned ten knots. On the morning of the first day at sea the vessels remained in formation slowly steaming into the direction of the primary swell between 0800 and 0900 while temporary repairs were made aboard the WHEC. As the steaming pattern was initiated one hour late, two octagonal legs were omitted during the last octagon of the first day at sea. Furthermore, during that day's last "octagon" the geometry was altered in order to place the vessels closer to port to expedite permanent repairs (the third course change of the last "octagon" was 130° to starboard, the fourth course change was 45° to port and the fifth course change was 90° to starboard). No perturbations in the steaming paradigm occurred during the second or third steaming days.

The lack of steaming pattern congruency between steaming days precluded comparisons between or within vessels as a function of either steaming pattern positions or time of day.

In addition to changes in the steaming procedure during the first day, examination of wave-rider buoy data, provided in Appendix G, shows both the average period of the seas and their significant heights to increase from the first to last steaming day ($p < .001$); however, sea states remained consistent during each eight hour steaming period. Although the day to day changes in sea state were small but statistically significant, sea state definitions provided in Appendix H show conditions remained within the criteria for a sea state across 3 steaming days.

Comparison of testing compartment translational motions data shows changes in wave height measures and vessel speeds across steaming days proved to be of little consequence aboard the SSP and WHEC. Aboard the WPB, daily test compartment frequency characteristics remained equivalent across days; however, small but statistically significant differences were found between daily means of compartment acceleration indices. Daily mean accelerations increased across steaming days, yet the range of accelerations experienced remained equivalent. For detailed presentation and discussion of the vessel motions data, see Woolaver et al. (1980).

In addition to sea state and steaming pattern changes mentioned, testing compartment temperatures were found to be cooler at sea aboard the WPB and SSP when compared to dockside levels ($p < .001$). Between vessel comparisons at sea show the WPB was slightly cooler than the other vessels ($p < .001$).

Testing compartment relative humidities increased from dockside to steaming conditions aboard the WPB and SSP ($p < .001$) while no significant differences were found aboard the WHEC. The WPB testing compartment was generally less humid than test compartments aboard the other vessels at sea ($p < .001$).

Appendix E provides test compartment temperature and relative humidity time series and vessel class plots along with statistical summaries.

Analysis of sound pressure level recordings within the testing compartments showed no statistically significant differences between vessels. See Appendix F for plots and analysis summary.

Despite efforts to control test compartment environments between and within experimental periods, small but statistically significant differences in some environmental parameters occurred. Where possible, and in the vast majority of statistical analyses performed, measures were taken to factor out such undesired contributions to subject responses.

In the initial set of analyses, which compare changes in dependent criteria from dockside to steaming conditions and between vessels at sea, no efforts were made to factor out contributions to the observed variance made by daily temperature and compartment acceleration shifts. A decision

was made to present results obtained with unadjusted data because efforts to adjust those data provided slightly more liberal outcomes or no significant changes.

Test compartment motions data provided in Appendix G reveal that the sea state experienced produced, in general, relatively stable motion environments aboard the WHEC and SSP. The SSP test compartment proved to be slightly more dynamic than that of the WHEC. The WPB produced a considerably more dynamic platform than the other vessels which led to significant physiological consequences.

Vessel Class Differences

Dependent variable data were examined for within vessel class differences between dockside and at-sea conditions and between vessel class differences at sea using a dichotomous variable regression technique described by Cohen and Cohen (1975). The technique, which is equivalent to a one-way analysis of variance (Edwards, 1976; Mosteller and Tukey, 1977), was employed because it eased data manipulation and provided additional statistical information.

Results of those analyses are summarized in Tables 4, 5, and 6.

Physiological measures were also examined for intervessel class differences during steaming days. The results of those dichotomous variable regression analyses are summarized in Table 7.

Findings obtained from both within and between vessel class dichotomous regression analyses show a significant increase in motion sickness symptomatology severity (MSSS) reports from dockside to steaming conditions aboard the WPB. Eighty-nine separate observed episodes of emesis occurred among sixteen subjects exposed to the motions aboard the WPB at sea (one subject voluntarily withdrew from the experiment after two hours of exposure to the WPB motions and resultant

TABLE 4--Comparisons between dockside and at sea mean responses for physiological measures taken aboard the SSP.

Measure	Dockside $\bar{x} \pm SE$	At Sea $\bar{x} \pm SE$	R^2	Source	Sums of Squares	df	Mean Square	F
Motion Sickness Symptomatology Severity Score	1.77 ± 1.44	1.80 ± 1. 4	.00	Treatment Residual	0.11 687.8	1 526	0.11 1.31	.08
Urine Output (ml/2hr)	500 ± 230	546 ± 230	.01	Treatment Residual	69559 6797229	1 128	69559 53103	1.3
Urine Specific Gravity	1.013 ± 0.010	1.013 ± 0.010	.08	Treatment Residual	10.2 15.320	1 128	10.2 119.7	0 1
Excretion Rate of 17-OHCS (mg/2hr)	1.88 ± 1.6	2.0 ± 1.6	.01	Treatment Residual	0.07 4.78	1 127	0.07 0.04	1.86
Excretion Rate of Catecholamines (μg/2hr)	1.7 ± 1.6	5.4 ± 3.2	.08	Treatment Residual	1.4 16.1	1 121	1.4 0.13	10.7 **
Heart Rate (beats/min)	70.9 ± 9.5	69.4 ± 9.5	.01	Treatment Residual	27479 4464017	1 496	27479 9000	3.1
Sweat Rate ml/cm 2hr/min	1.4×10^{-3} ± 1.7×10^{-3}	1.6×10^{-3} ± 1.7×10^{-3}	.00	Treatment Residual	25 5520	1 521	25 10.6	2.3

* $p < .05$ ** $p < .01$ *** $p < .001$

TABLE 5--Comparisons between dockside and at sea responses for physiological measures taken aboard the WPB.

Measure	Dockside $\bar{x} \pm SE$	At Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Motion Sickness Sympt. Severity Score (MSSS)	1.5 ± 1.7	5.0 ± 1.7	.52	Treatment Residual	1594 1505	1 526	1594 2.9	557 ***
Urine Output (ml/2 hr)	450 ± 226	180.8 ± 226	.26	Treatment Residual	232532 6544764	1 126	232532 51943	45 ***
Urine Specific Gravity	1.015 ± 0.01	1.030 ± 0.01	.31	Treatment Residual	4752 10385	1 115	4752 90	53 ***
17-OHCS Excretion Rate (mg/2 hr)	1.0 ± 0.6	2.6 ± 0.6	.13	Treatment Residual	.99 6.87	1 116	99 .06	17 ***
Catecholamine Excretion Rate (µg/2 hr)	4.8 ± 2.8	5.0 ± 2.8	.00	Treatment Residual	0.008 22.55	1 116	0.008 0.194	.04
Heart Rate (beats/min)	71.6 ± 11.1	72.4 ± 11.1	.00	Treatment Residual	6764 5069353	1 452	6764 11215	0.6
Sweat Rate ml/cmh	$1.5 \times 10^{-3} \pm 1.8 \times 10^{-3}$	$1.4 \times 10^{-3} \pm 1.8 \times 10^{-3}$	.00	Treatment Residual	2.5 4952	1 415	2.5 11.9	.21

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 6--Comparisons between dockside and at sea responses for physiological measures taken aboard the WHEC.

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	h^2	Source	SS	df	MS	F
Motion Sickness Symptomatology Severity Score	1.86 ± 1.20	1.96 ± 1.20	.00	Treatment Residual	1.4 759.7	1 526	1.4 1.4	1.0
Urine Output (ml/2 hr)	376 ± 234	426 ± 234	.01	Treatment Residual	85752 7393740	1 134	85752 55177	1.6
Urine Specific Gravity	$1.081 \pm .011$	$1.017 \pm .011$	.08	Treatment Residual	11.4 14931	1 132	11.4 113.1	0.1
Excretion Rate 17-OHCS (mg/2 hr)	1.6 ± 1.6	1.8 ± 1.6	.03	Treatment Residual	0.169 5.072	1 132	0.169 0.038	4.4 **
Excretion Rate of Catecholamine (μg/2 hr)	4.0 ± 2.4	5.3 ± 2.4	.02	Treatment Residual	0 46 18.27	1 128	0.46 0.14	3.2
Heart Rate (beats/min.)	70.9 ± 9.5	72.4 ± 9.5	.01	Treatment Residual	27479 4464017	1 496	27479 9000	3.1
Sweat Rate $ml.cm.^{-1}min^{-1}$	$1.5 \times 10^{-3} \pm 2.0 \times 10^{-3}$	$1.6 \times 10^{-3} \pm 2.0 \times 10^{-3}$	.00	Treatment Residual	15 7977	1 527	16 15.1	1.04

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 7--Comparisons of mean responses for physiological measures taken aboard the SSP, WPB and WHEC at sea.

Measure	SSP $\bar{x} \pm SE$	WPB $\bar{x} \pm SE$	WHEC $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Motion Sickness Symptomatology Severity	1.8 ± 1.6	5.0 ± 1.6	1.8 ± 1.6	.69	Treatment Residual	1768 1894	2 781	884 2.4	365 ***
Urine Output (ml/2 hr)	546 ± 234	180 ± 234	426 ± 234	.54	Treatment Residual	4384836 10599701	2 193	2192418 54921	39.9 ***
Urine Specific Gravity	1.013 ± 0.01	1.028 ± 0.01	$1.018 \pm .01$	.52	Treatment Residual	6264 17138	2 182	3132 94	33.3 ***
Excretion of 17-OHCS (mg/2 hr)	2.2 ± 0.2	3.4 ± 0.2	1.0 ± 0.2	.23	Treatment Residual	0.414 7.648	2 182	0.207 0.0420	4.95 ***
Excretion Rate of Catecholamine (μg/2 hr)	5.3 ± 2.3	5.2 ± 2.3	5.2 ± 2.3	.01	Treatment Residual	0.003 23.33	2 177	0.002 0.132	0.01
Heart Rate (beats/min)	69.4 ± 10.4	72.5 ± 10.4	72.4 ± 10.4	.14	Treatment Residual	157761 8111669	2 746	78881 10874	7.3 **
Sweat Rate $ml.cm.^{-1}min^{-1}$	$1.6 \times 10^{-3} \pm 1.0 \times 10^{-3}$	$1.6 \times 10^{-3} \pm 1.8 \times 10^{-3}$	$2.1 \times 10^{-3} \pm 1.0 \times 10^{-3}$	.10	Treatment Residual	.51 79.7	2 508	.25 .10	2.6

*$p < .05$
**$p < .01$
***$p < .001$

motion sickness and one subject who experienced moderate to severe levels of nausea did not vomit during the eight hour exposure). No significant increases in MSSS reports were found from dockside to steaming conditions aboard either the SSP or WHEC (See Figure 7).

The low MSSS scores obtained aboard all vessels during dockside peridos may be attributed to reports of thermal sweating as well as general discomfort, fatigue and headaches associated with eight hours of conitinuous performance testing. Although it would have been possible to null out such reports by reducing the sensitivity of the scaling method, loss of such information was considered to be disadvantageous and no such efforts were made.

Breakdown of MSSS scores for each vessel during each day at sea shows a slight decline in severity scores as the days progressed, despite growing seas and slight increases in vessel motion severity.

TABLE 8--Average motion sickness symptomatology scores obtained aboard vessels during each steaming day

	WPB	SSP	WHEC	$\bar{x}$
Day 1	4.95	2.18	2.42	3.18
Day 2	5.72	1.86	2.25	3.27
Day 3	4.81	1.32	1.21	2.56
$\bar{x}$	5.16	1.89	1.96	3.00

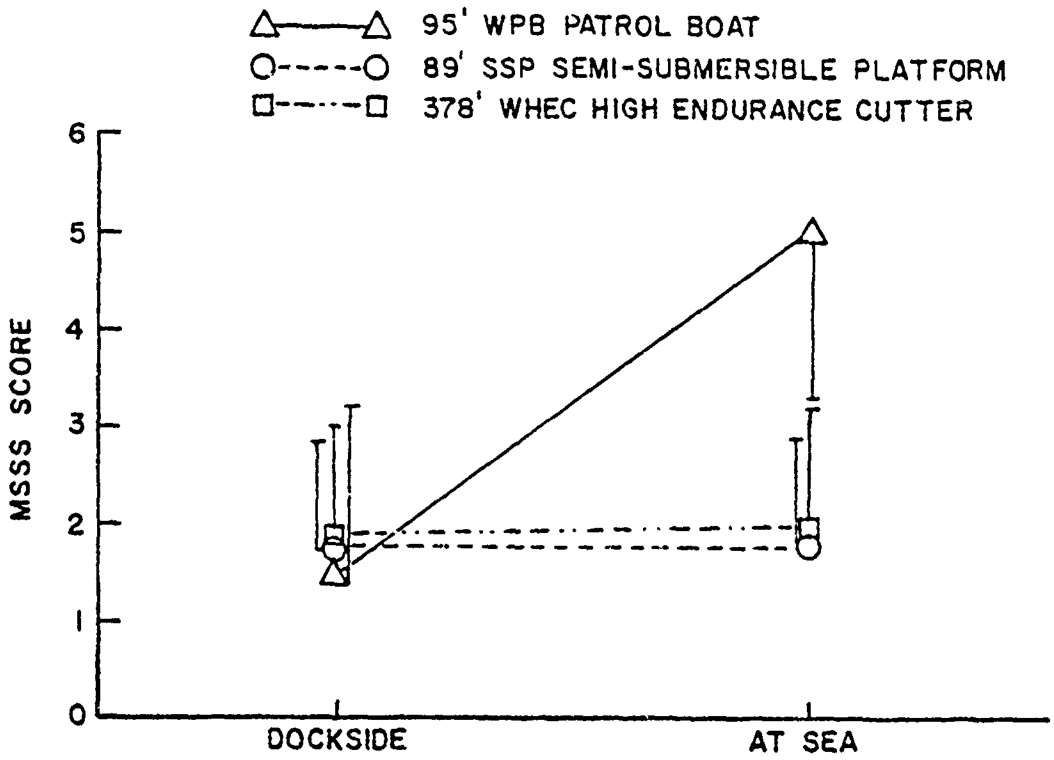


FIGURE 7--Mean response and standard error of motion sickness symptomatology severity scores as a function of vessel class and testing condition.

Figure 8 shows that changes in steaming course, and consequently the motion environment, led to recurring changes in MSSS reports aboard the WPB. The relationship between the motion environment's characteristics and motion sickness severity is discussed later.

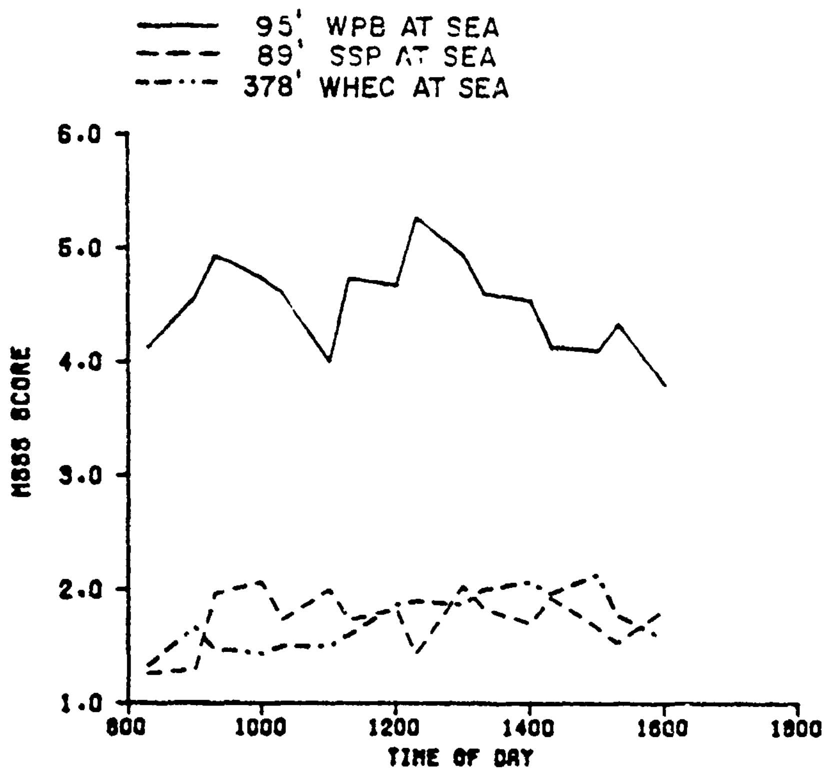


FIGURE 8--Average motion sickness symptomatology severity (MSSS) scores for each vessel class during days at sea.

Urine output did not change significantly between dockside and steaming conditions aboard either the SSP or WHEC. The motion environment and subsequent motion sickness aboard the WPB, however, led to an average reduction in two-hour urine

output of 60.0% (p < .001). See Figure 9.

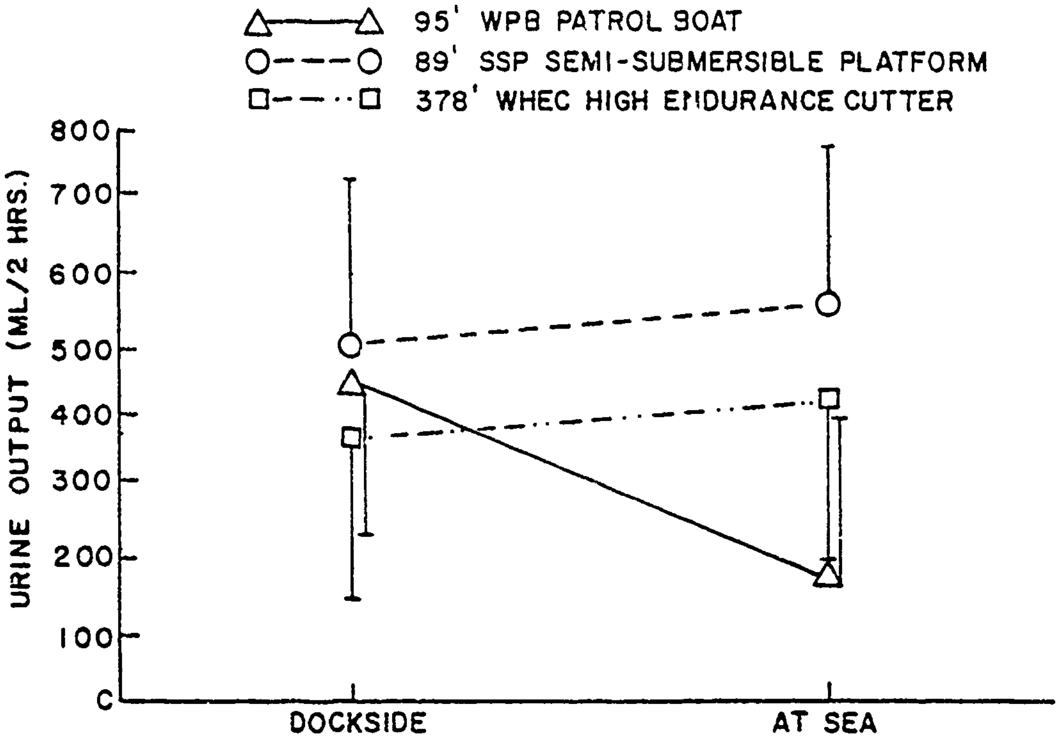


FIGURE 9--Mean response and standard error of urine output per two-hour period as a function of vessel class and testing condition.

Comparisons of urine output data among vessel classes at sea shows urine output curves for the SSP and WHEC to be similar in form to those seen for dockside data, while the WPB curve shows a sustained depression until the latter part of the day when motion sickness severity declined somewhat. Urine output was greater aboard the SSP than either the WHEC or WPB with the WPB yielding significantly lower specimen volumes than either the SSP or WHEC. See Figure 10.

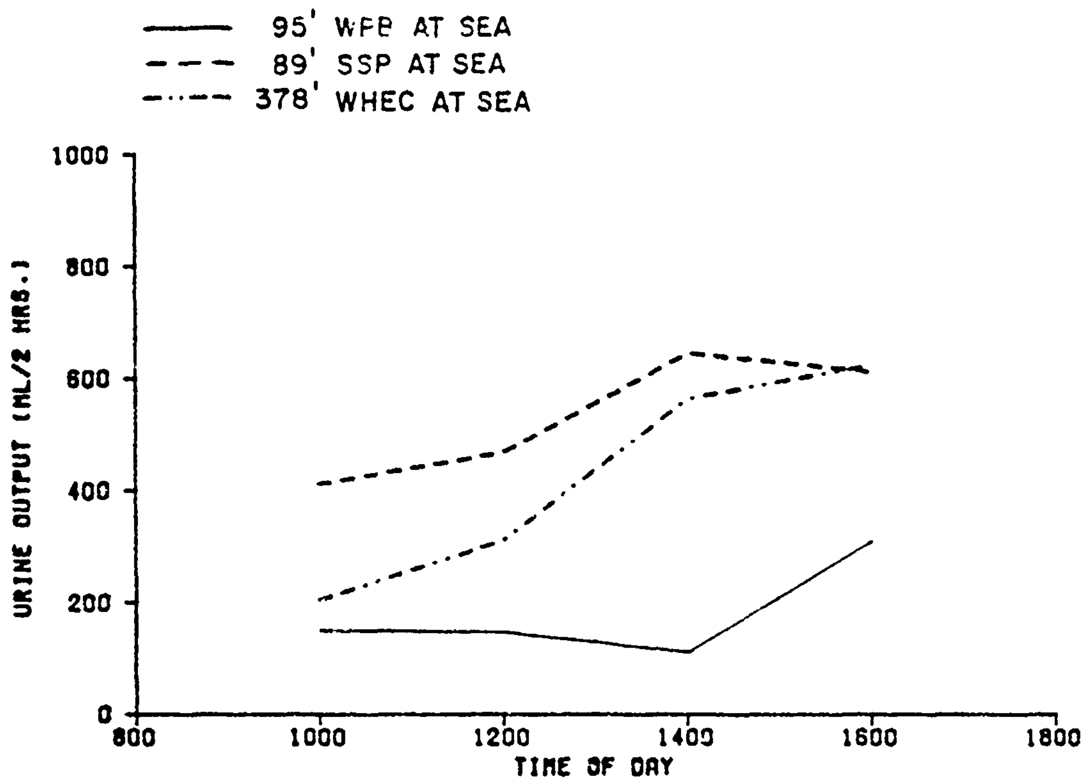


FIGURE 10--Average urine output aboard each vessel during steaming days.

As with urine output, urine specific gravity levels were unchanged from dockside to steaming conditions aboard the SSP and WHEC. Conditions aboard the WPB at sea led to a significant increase in urine specific gravity from dockside values ($\bar{\Delta}$ = 100.0%, $p < .001$).

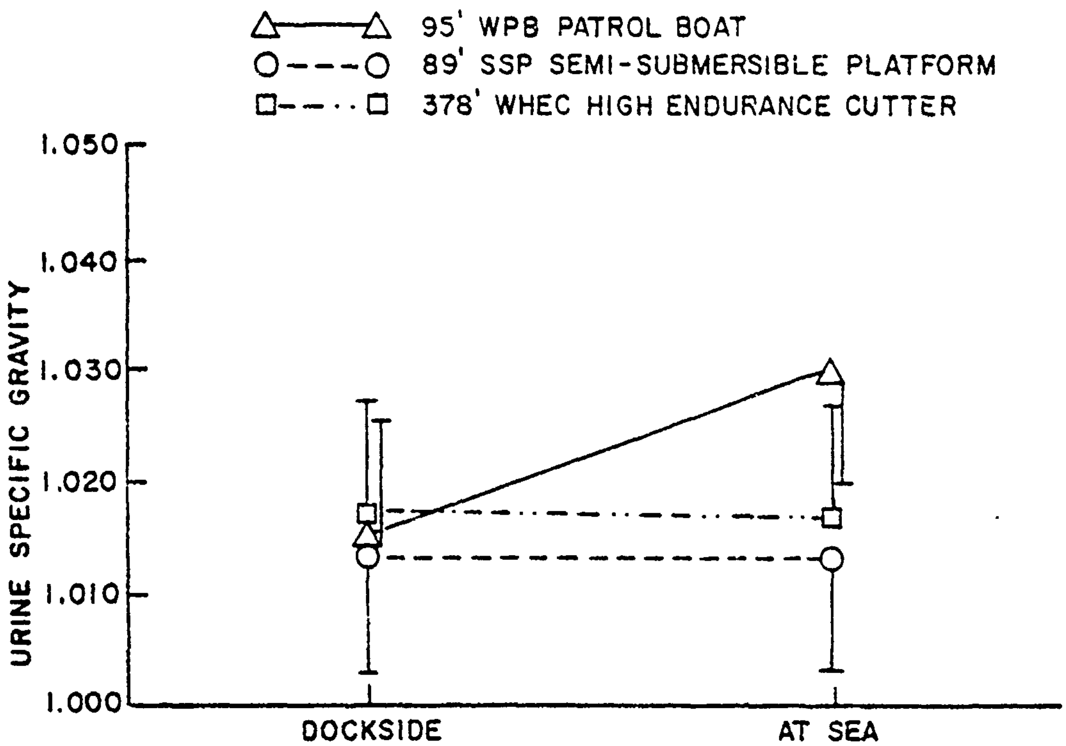


FIGURE 11--Mean response and standard error of urine specific gravity per two-hour period as a function of vessel class and testing condition.

Examination of average at-sea values for urine specific gravity shows time series curves for the SSP and WHEC to be similar in form to dockside responses, yet the specific gravities were lower aboard the SSP than the WHEC. As the subjects drank 240 ml. of fluid each thirty minutes, urine samples were more dilute as output increased. The WPB on the other hand shows a sustained elevation in specific gravity values throughout the day at sea.

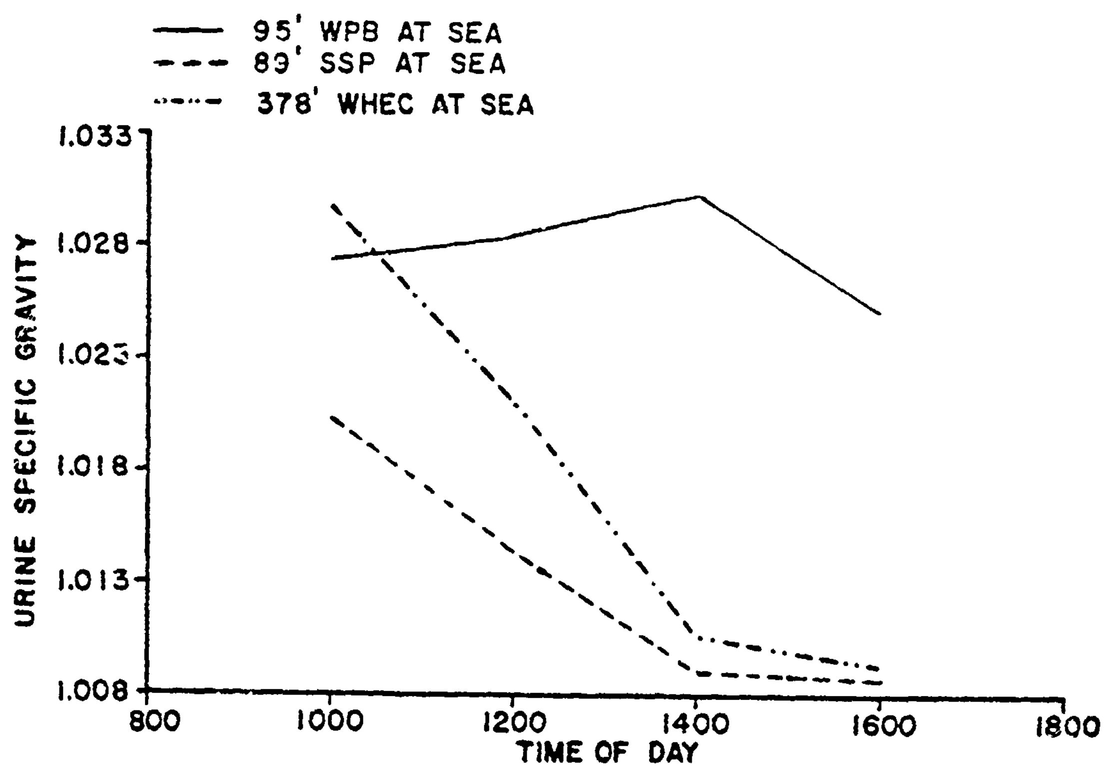


FIGURE 12--Average urine specific gravity aboard each vessel during steaming days.

It is interesting to note that differences among vessels at sea in both urine output and specific gravity did not become clear until four hours following initial test compartment motion exposure. This is in spite of the fact that motion sickness onset was rapid and severe aboard the WPB (generally most subjects had experienced severe symptoms of motion sickness by 0830 each day).

No significant change in urinary excretion rate of 17-OHCS was found aboard the SSP between dockside and steaming conditions. Steaming conditions led to an 18.8% ($p < .01$) elevation

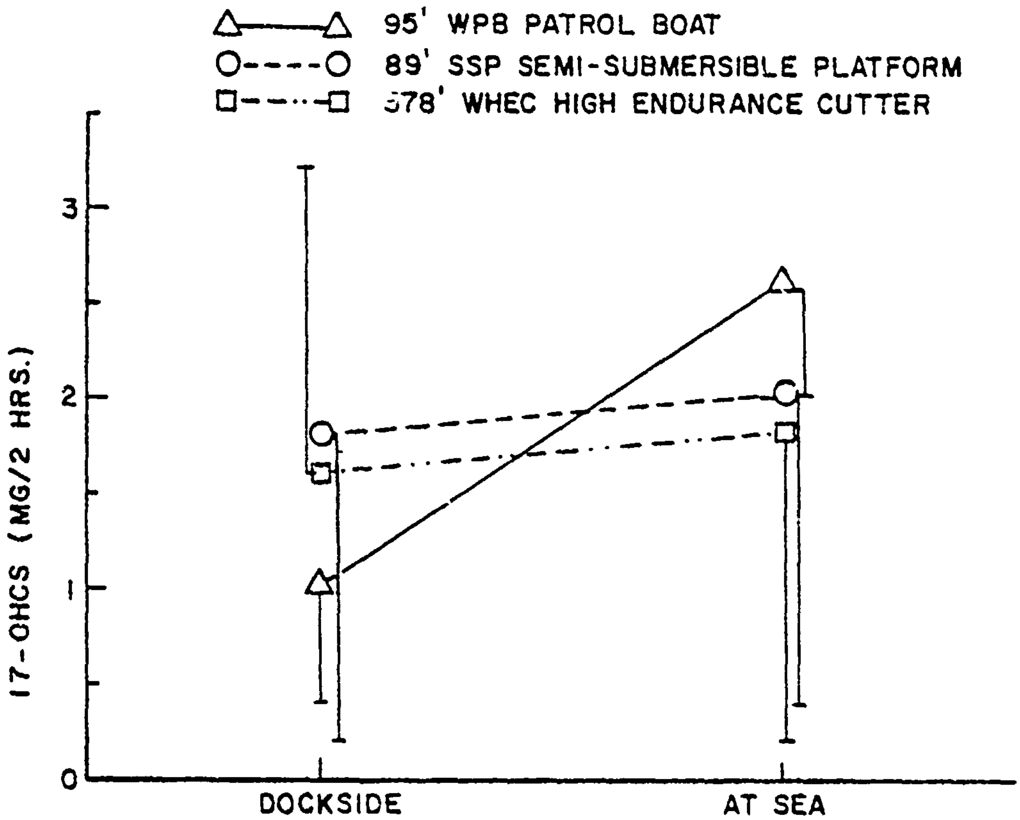


FIGURE 13--Mean response and standard error of urinary 17-OHCS excretion rates per two-hour period as a function of vessel class and testing condition.

in 17-OHCS excretion rate from dockside levels aboard the WHEC while exposure to the WPB produced a 160.0% ($p < .001$) increase.

Examination of 17-OHCS excretion rates between vessels at sea shows significant differences between all vessels. The average excretion rate of 17-OHCS aboard the WPB was 230.0% ($p < .01$) greater than that observed aboard the WHEC and 51.1% ($p < .01$) greater than that of the SSP. Excretion rates aboard the SSP averaged 120.0% ($p < .01$) greater than those found aboard the WHEC.

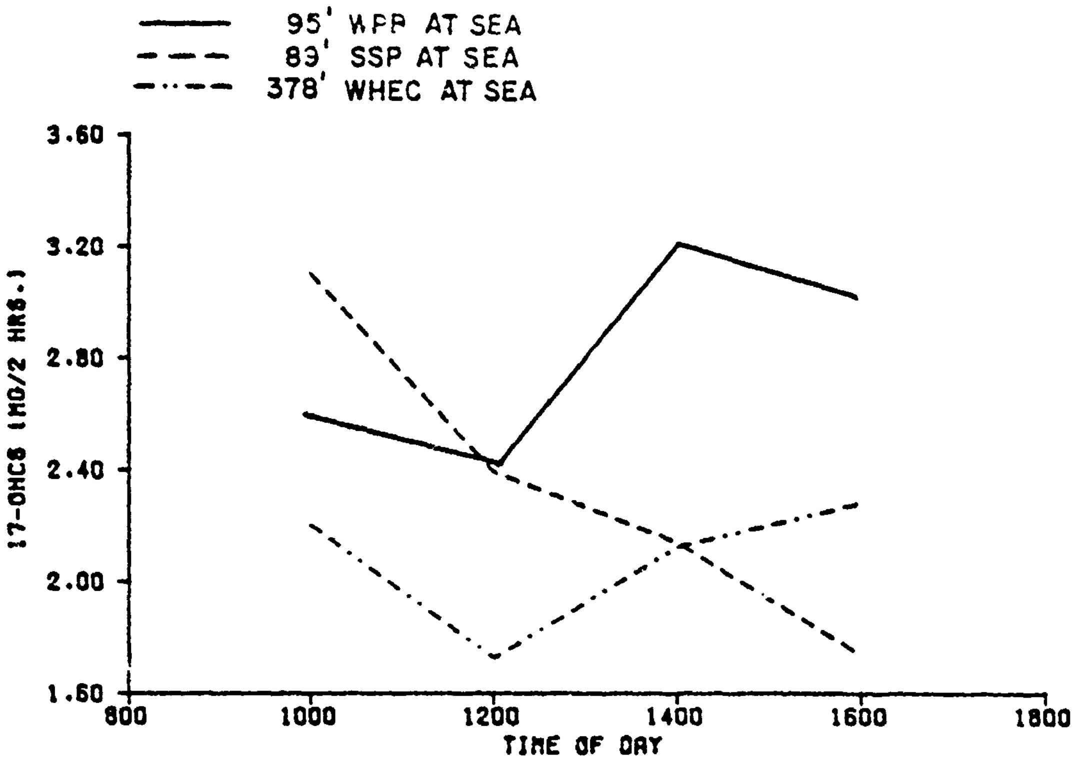


FIGURE 14--Average urinary 17-OHCS excretion rate per two-hour period aboard each vessel during steaming days.

Comparisons between dockside and at-sea urinary catecholamine excretion rates show significant elevations at sea aboard the SSP ($\bar{\Delta}$ = 58.8%, $p < .01$); however, no significant changes were found for either the WPB or WHEC in similar analyses.

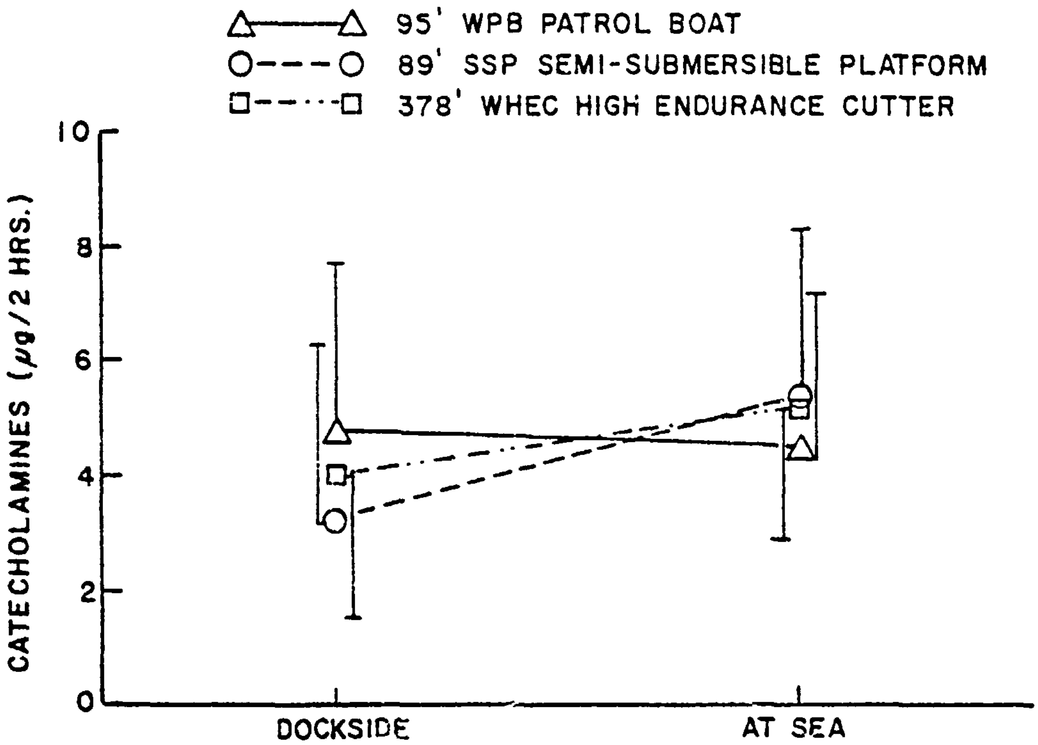


FIGURE 15--Mean response and standard error of urinary catecholamine excretion rates per two-hour period as a function of vessel class and testing condition.

Analysis of urinary catecholamine excretion rates during steaming days indicated there were no significant differences among the vessels.

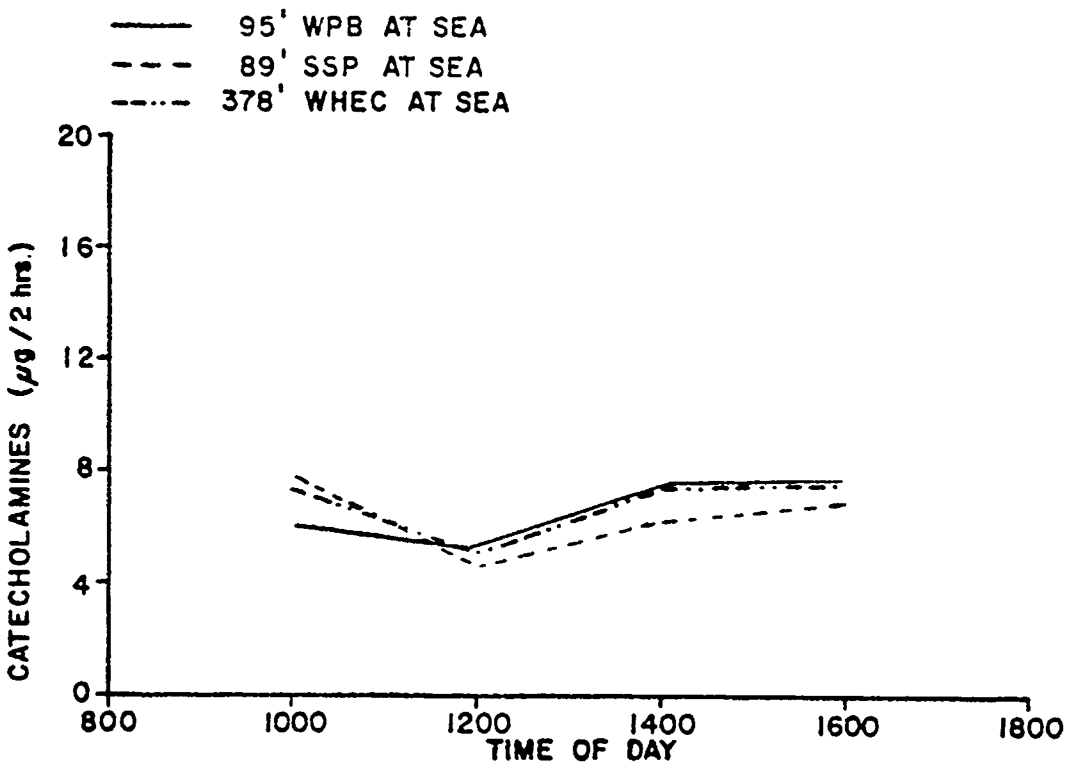


FIGURE 16--Average urinary catecholamine excretion rates per two-hour period aboard each vessel during steaming days.

Comparisons between mean heart rates dockside and at sea obtained during the first twenty-five minutes of each cycle showed no differences within any of the vessels.

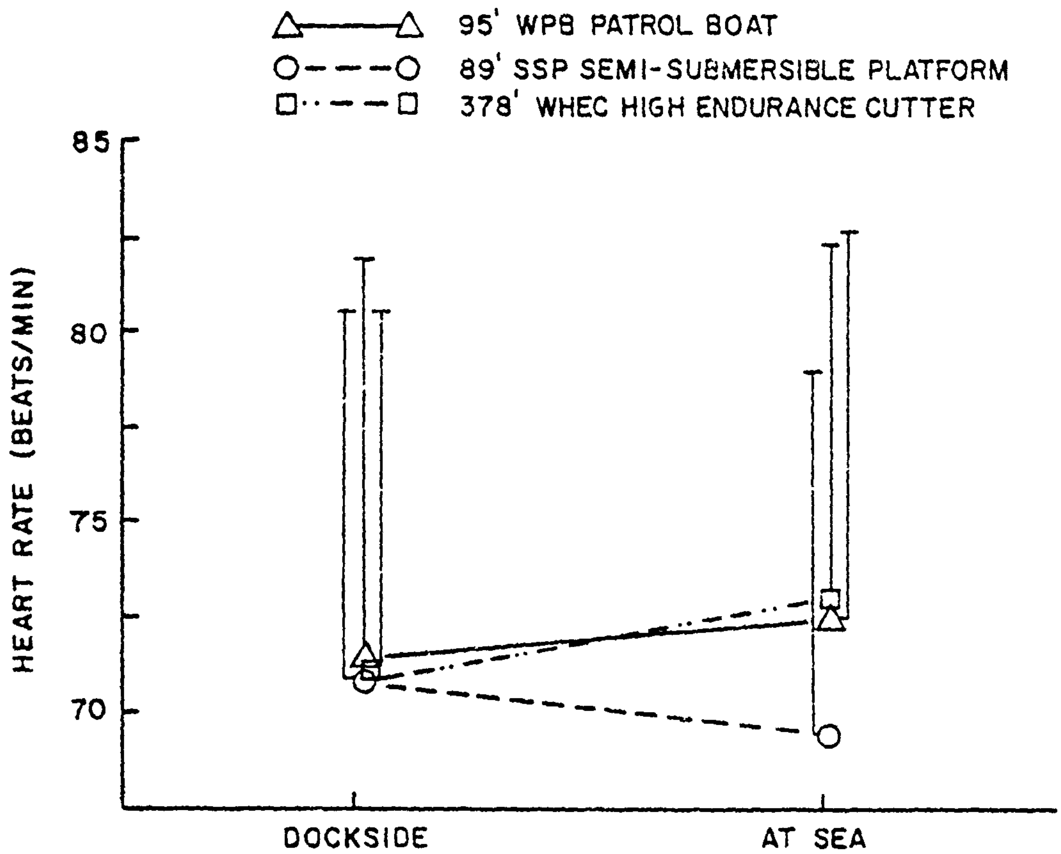


FIGURE 17--Mean response and standard error of heart rates as a function of vessel class and testing condition.

Although there was a general decline in heart rate at sea aboard the WPB and WHEC as the day progressed, no differences were found among the three vessels.

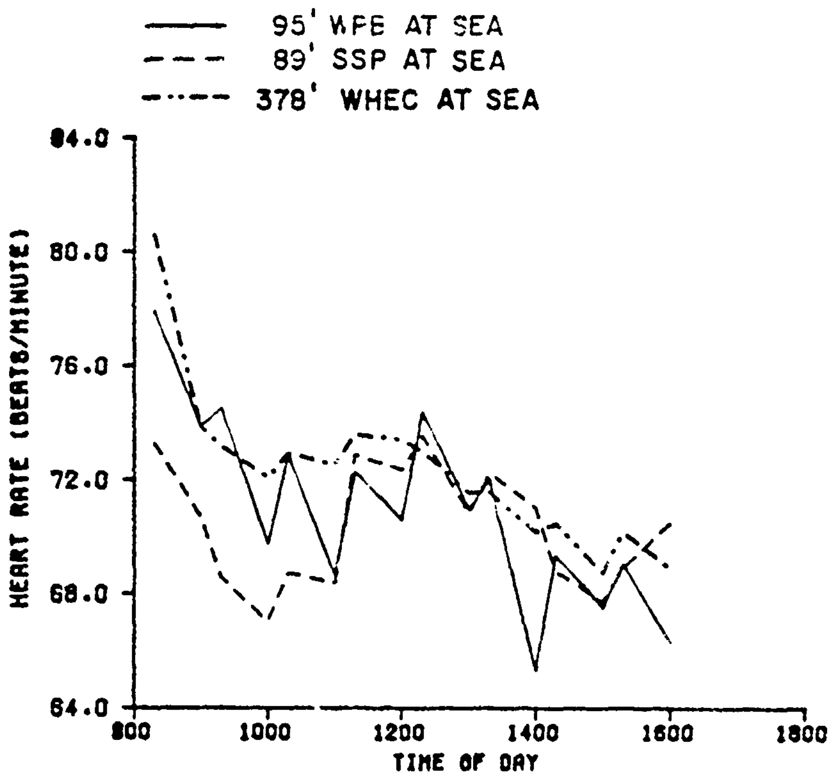


FIGURE 18--Average heart rate aboard each vessel during steaming days.

Comparisons of dockside versus at-sea forehead sweat rates showed no differences within any of the three vessels. See Figure 19.

Highly variable sweat rate data collected at sea showed no significant differences among vessels as shown in Figure 20.

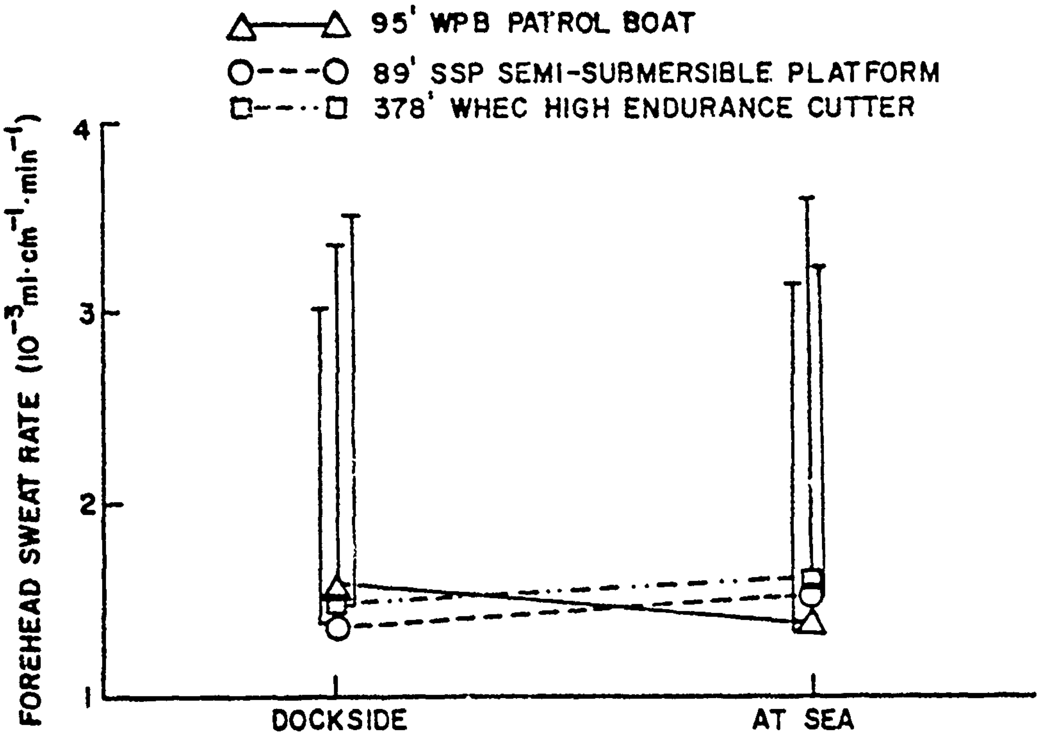


FIGURE 19--Mean response and standard error of sweat rates as a function of vessel class and testing condition.

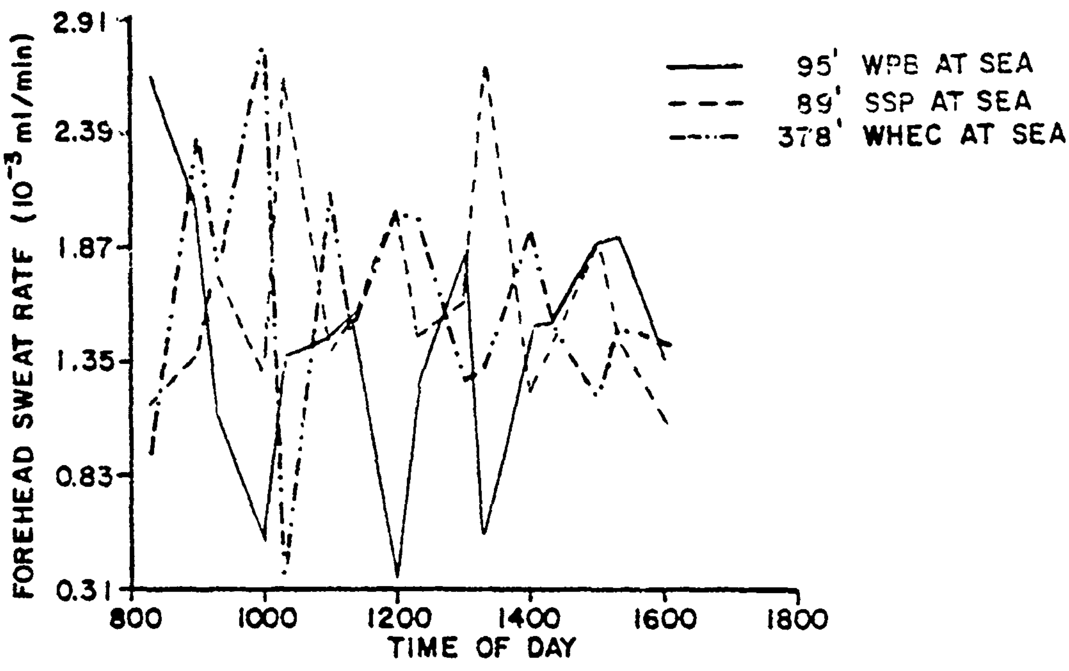


FIGURE 20--Average sweat rate aboard each vessel during steaming days.

Vessel Class Differences In Affective State

Mood dimensions were examined within each vessel class for significant changes from dockside to steaming conditions aboard all vessels using the dicholomous variable regression technique described earlier. Results obtained are summarized in Tables 9, 10, and 11. Mood adjective check list (MACL) responses were also examined for vessel class differences at sea (See Table 12).

Examination of subject MACL's showed no significant changes in mood from dockside to steaming conditions occurred aboard the SSP and WHEC with the exceptions of small increases in reports of social affection and surgency aboard the WHEC. The WPB environment at sea, however, led to significant changes in all mood dimensions examined with the exceptions of egotism, skepticism and social affection.

Comparison of MACL data collected at sea shows with the exception of heightened anxiety aboard the SSP, there were no significant differences between mood levels aboard the WHEC and SSP. The WPB, however, produced substantial differences in mood in every dimension examined, excepting social affection, when compared to the other two vessels.

Table 9--Comparisons between dockside and at-sea means for affective state dimensions measured aboard the SSP.

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.45 ± 0.52	0.21 ± 0.52	0.0005	Treatment Residual	0.07 147.78	1 542	0.07 0.27	0.3
Anxiety	0.38 ± 0.63	0.39 ± 0.63	0.0005	Treatment Residual	0.10 181.63	1 542	0.10 0.34	0.3
Concentration	1.51 ± 1.02	1.59 ± 1.02	0.002	Treatment Residual	0.98 566.69	1 542	0.98 1.05	0.9
Egotism	0.50 ± 0.73	0.50 ± 0.73	0.0001	Treatment Residual	0.53 5249	1 542	0.53 9.68	0.05
Elation	0.57 ± 0.53	0.52 ± 0.53	0.002	Treatment Residual	0.92 153.03	1 542	0.92 0.28	1.0
Fatigue	0.77 ± 0.92	0.80 ± 0.92	0.0003	Treatment Residual	0.24 463.16	1 542	0.24 0.85	0.2
Sadness	0.14 ± 0.48	0.19 ± 0.48	0.003	Treatment Residual	0.34 125.72	1 542	0.34 0.23	1.5
Skepticism	0.30 ± 0.50	0.26 ± 0.50	0.002	Treatment Residual	0.23 135.5	1 542	0.23 0.25	0.9
Social Affection	0.51 ± 0.69	0.48 ± 0.69	0.0006	Treatment Residual	0.15 256.66	1 542	0.15 0.47	0.3
Surgency	0.67 ± 0.66	0.68 ± 0.66	0.00002	Treatment Residual	0.01 2?7.87	1 542	0.01 0.44	0.01
Vigor	1.10 ± 0.93	1.03 ± 0.93	0.001	Treatment Residual	0.60 470.6	1 542	0.60 0.87	0.7

* p .05
** p .01
*** p .001

Note: Moods were scored as -- 0- Definitely Not
1- Undecided
2- Slightly
3- Definitely

Table 10--Comparisons between dockside and at-sea means for affective state dimensions measured aboard the WPB.

Measure	Dockside $\bar{X} \pm SE$	At Sea $\bar{X} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.21 ± 0.78	0.60 ± 0.78	0.01	Treatment Residual	4.55 323.35	1 526	4.55 0.62	7.4**
Anxiety	0.36 ± 0.70	0.80 ± 0.70	0.10	Treatment Residual	29.80 258.17	1 526	29.80 0.49	60.7***
Concentration	1.52 ± 0.96	1.12 ± 0.96	0.04	Treatment Residual	21.27 489.62	1 526	21.27 0.93	22.9***
Egotism	0.40 ± 0.65	0.38 ± 0.65	0.0003	Treatment Residual	0.08 224.82	1 526	0.08 0.43	0.2
Elation	0.51 ± 0.57	0.20 ± 0.57	0.07	Treatment Residual	12.72 168.54	1 526	12.72 0.32	39.7***
Fatigue	1.00 ± 0.93	1.83 ± 0.93	0.17	Treatment Residual	90.17 454.98	1 526	90.17 0.86	104.2 ***
Sadness	0.18 ± 0.70	0.71 ± 0.70	0.13	Treatment Residual	36.44 255.59	1 526	36.44 0.49	75.0***
Skepticism	0.43 ± 0.74	0.52 ± 0.74	0.004	Treatment Residual	1.25 287.90	1 526	1.25 0.55	2.3
Social Affection	0.45 ± 0.64	0.37 ± 0.64	0.004	Treatment Residual	0.90 214.40	1 526	0.90 0.41	2.2
Surgency	0.62 ± 0.57	0.14 ± 0.57	0.15	Treatment Residual	31.24 181.12	1 526	31.24 0.34	90.7***
Vigor	0.96 ± 0.77	0.29 ± 0.77	0.16	Treatment Residual	60.14 310.38	1 526	60.14 0.59	101.9 ***

* p .05
** p < .01
*** p < .001

Note: Moods were scored as -- 0 - Definitely Not, 1 - Undecided, 2 - Slightly, 3 - Definitely

Table 11--Comparisons between dockside and at-sea means for affective state dimensions measured aboard the WHEC.

Measure	Dockside $\bar{x} \pm SE$	At Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.23 ± 0.56	0.25 ± 0.56	0.0005	Treatment Residual	0.88 167.77	1 542	0.08 0.31	0.03
Anxiety	0.28 ± 0.47	0.24 ± 0.47	.002	Treatment Residual	0.28 117.82	1 542	0.28 0.22	1.3
Concentration	1.52 ± 1.06	1.5 ± 1.06	0.00005	Treatment Residual	0.03 613.93	1 542	0.03 1.13	0.03
Egotism	0.55 ± 0.75	0.52 ± 0.75	0.0005	Treatment Residual	0.16 305.30	1 542	0.16 0.56	0.3
Elation	0.45 ± 0.54	0.42 ± 0.54	0.0007	Treatment Residual	0.11 157.44	1 542	0.11 0.29	0.4
Fatigue	0.86 ± 0.93	0.90 ± 0.93	0.0004	Treatment Residual	0.21 470.26	1 542	0.21 0.87	0.2
Sadness	0.09 ± 0.38	0.19 ± 0.38	0.02	Treatment Residual	1.27 78.11	1 542	1.27 0.14	8.8**
Skepticism	0.33 ± 0.51	0.26 ± 0.51	0.005	Treatment Residual	0.67 139.57	1 542	0.67 0.26	2.6
Social Affection	0.33 ± 0.63	0.46 ± 0.63	0.01	Treatment Residual	2.40 215.19	1 542	2.40 0.40	6.0*
Surgency	0.61 ± 0.73	0.74 ± 0.73	0.008	Treatment Residual	2.40 286.54	1 542	2.40 0.53	4.5*
Vigor	1.14 ± 0.92	1.09 ± 0.92	0.0009	Treatment Residual	0.40 460.22	1 542	0.40 0.85	0.5

* p .05
** p .01

Note: Moods were scored as -- 0 - Definitely Not 1 - Undecided 2 - Slightly 3 - Definitely

Table 1[illegible]--Comparisons of means for affective state dimensions measures taken aboard the SSP, WPB and WHEC at sea.

Measure	SSP $\bar{x} \pm SE$	WPB $\bar{x} \pm SE$	WHEC $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Aggression	0.21 ± 0.67	0.59 ± 0.67	0.25 ± 0.67	0.06	Treatment Residual	22 363	2 797	11 0.5	24.4***
Anxiety	0.40 ± 0.61	0.81 ± 0.61	0.24 ± 0.61	0.13	Treatment Residual	45.8 303.0	2 797	22.9 0.4	60.2***
Concentration	1.6 ± 1.0	1.1 ± 1.0	1.9 ± 1.0	0.04	Treatment Residual	33 788	2 797	16.4 0.99	16.6***
Egotism	0.5 ± 0.71	0.38 ± 0.71	0.52 ± 0.71	0.008	Treatment Residual	3.1 403.1	2 797	1.53 0.51	3.0*
Elation	0.52 ± 0.47	0.20 ± 0.47	0.42 ± 0.47	0.07	Treatment Residual	14 176	2 797	7.0 0.2	31.3***
Fatigue	0.80 ± 0.93	1.83 ± 0.93	0.91 ± 0.93	0.19	Treatment Residual	167 694	2 797	83.6 0.9	96.1***
Sadness	0.19 ± 0.65	0.70 ± 0.65	0.19 ± 0.65	0.12	Treatment Residual	46.5 332.6	2 797	23.3 0.42	55.4***
Skepticism	0.26 ± 0.60	0.52 ± 0.60	0.26 ± 0.60	0.04	Treatment Residual	12 281	2 797	6.0 0.4	15.0***
Social Affection	0.48 ± 0.67	0.37 ± 0.67	0.47 ± 0.67	0.005	Treatment Residual	1.8 358.9	2 797	0.92 0.45	2.0
Surgency	0.68 ± 0.63	14 ± 0.63	0.74 ± 0.63	0.15	Treatment Residual	57 315	2 797	28.5 0.4	72.2***
Vigor	1.03 ± 0.82	0.29 ± 0.8[illegible]	1.09 ± 0.82	0.16	Treatment Residual	103.7 539.1	2 797	51.8 0.7	76.6***

* $p < .05$
** $p < .01$
*** $p < .001$

Note: Moods were scored as -- 0 - Definitely Not, 1 - Undecided, 2 - Slightly, 3 - Definitely

Subject reports of aggression increased from dockside to steaming conditions aboard the WPB ($p < .01$) while no changes were found in the data collected aboard the other two vessels. See Figure 21.

Direct comparison of aggression MACL data collected at sea shows no significant differences between the SSP and WHEC. Figure 22 on the following page shows feelings of aggression were greater aboard the WPB than the other vessel; however, the average aggression score varied between levels "definitely not" and "uncertain".

Reports of anxiety increased from dockside to steaming conditions aboard the WPB ($p < .001$) while no differences were found aboard either the SSP or WHEC. See Figure 23.

Although significant differences were found in anxiety scores abtained between the vessels at dockside, there were differences aboard all three vessels during the days at sea. Reports of anxiety aboard the WPB at sea were greater than those obtained aboard the SSP or WHEC ($p <$ 01). Anxiety reports obtained aboard the SSP during steaming days were greater than those aboard the WHEC. With the exception of early morning reports aboard the WPB when motion sickness onset was abrupt, subject anxiety remained fairly stable throughout the steaming period aboard all vessels. The spike seen in the WHEC plot of anxiety reports resulted from a few subjects reporting near maximum degrees of anxiety during the second to last steaming day. Why such a rapid

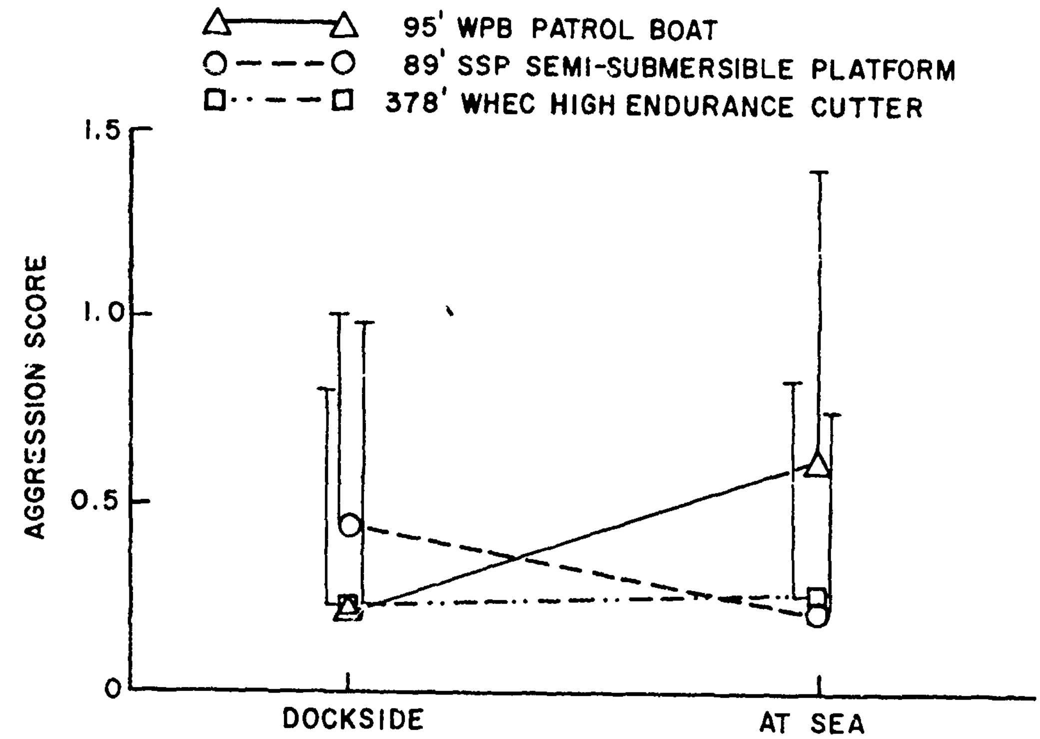


Figure 21--Mean response and standard error of aggression reports for vessel class and testing condition.

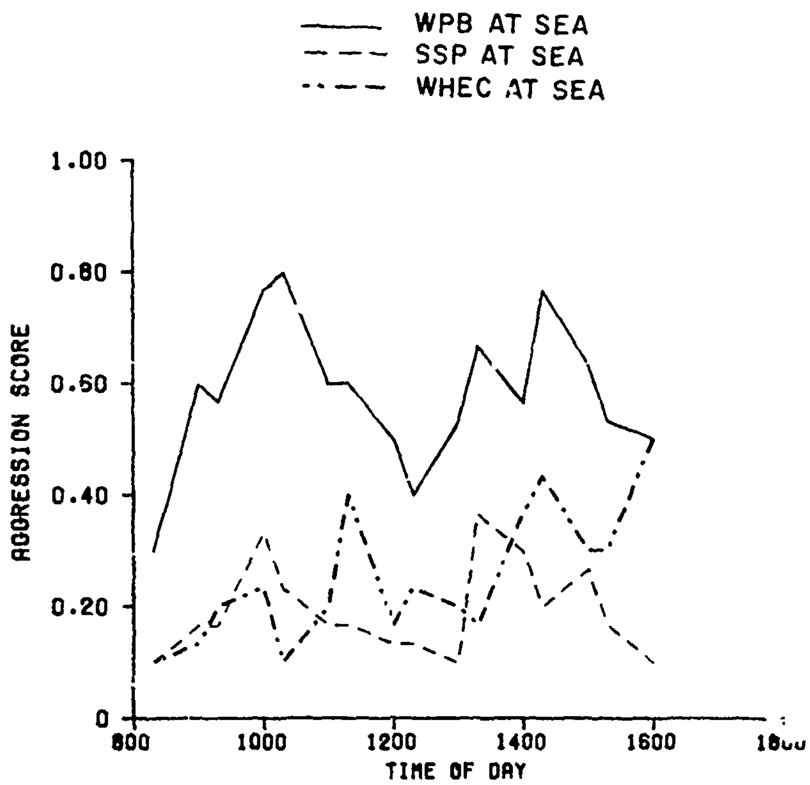


Figure 22--Average report of aggression aboard each vessel during steaming days.

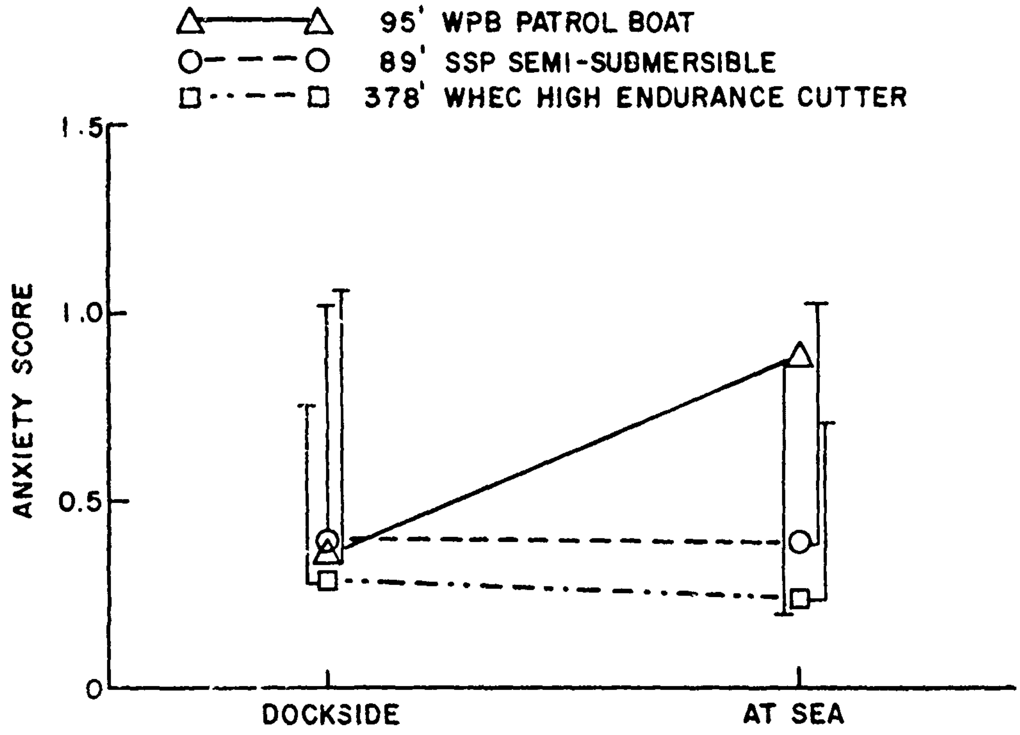


Figure 23--Mean response and standard error of anxiety reports for vessel class and testing condition.

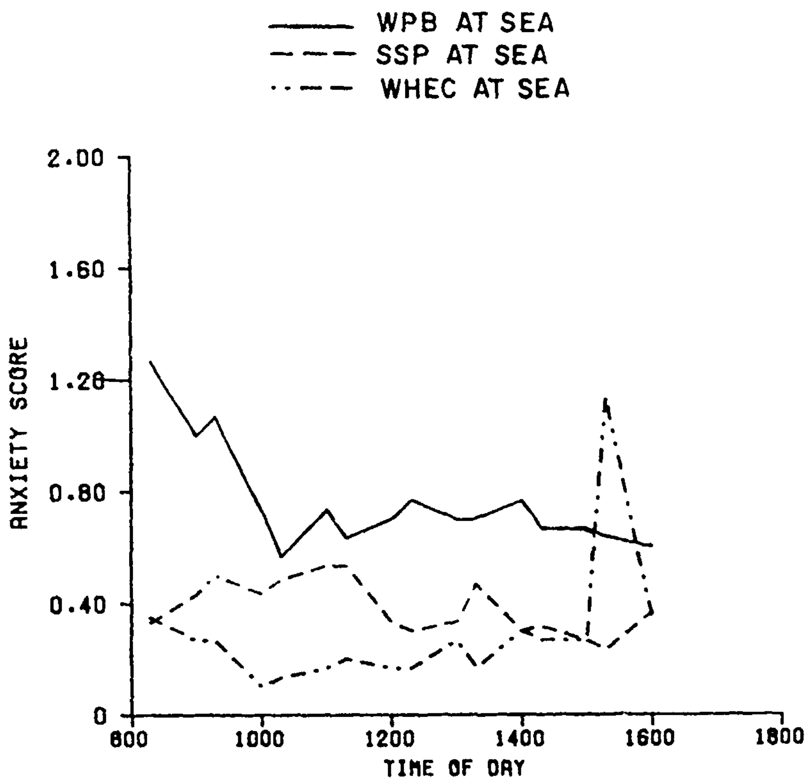


Figure 24--Average report of anxiety aboard each vessel during steaming days.

increase and decline in their reports of anxiety occurred could not be determined from the available data, however, given the rapid return to report levels preceeding the spike it is believed those subjects may have mischecked their questionnaires. See Figure 24.

Subject responses to adjectives concerning concentration did not change from dockside to steaming conditions aboard the SSP or WHEC. A decline in the subjects' report of concentration was found at sea aboard the WPB when compared to dockside levels ($p < .001$). See Figure 25.

No differences in reports of concentration were found between vessels during dockside periods, however, at sea differences were found between all vessels. Exposure to the WPB at sea led to lower reports of concentration than those obtained aboard the SSP ($p < .05$) or the WHEC ($p < .001$). Reports of concentration were lower aboard the SSP at sea than those aboard the WHEC ($p < .001$).

As shown in Figure 26 subjects reported highest levels of concentration in the mornings, which wanned slowly as the day progressed.

No significant differences were found between dockside and steaming day reports of egotism aboard any vessel. See Figure 27.

Comparison of egotism scores obtained at sea aboard the SSP and WHEC shows no significant differences between the vessels. Reports obtained from the WPB during the steaming

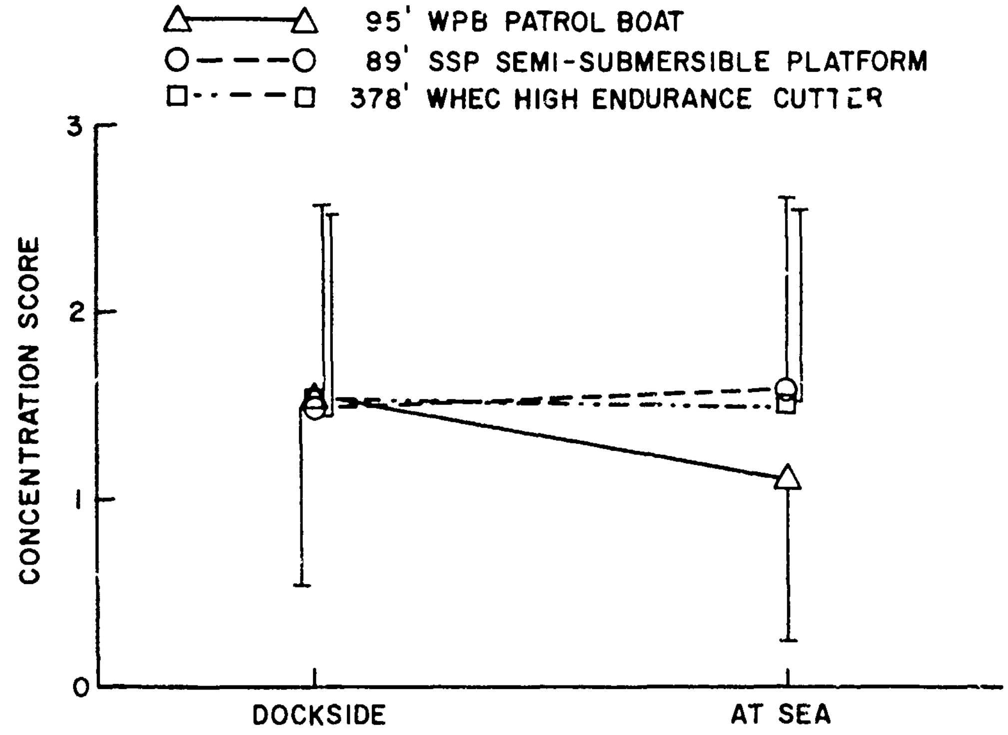


Figure 25--Mean response and standard error of concentration reports for vessel class and testing condition.

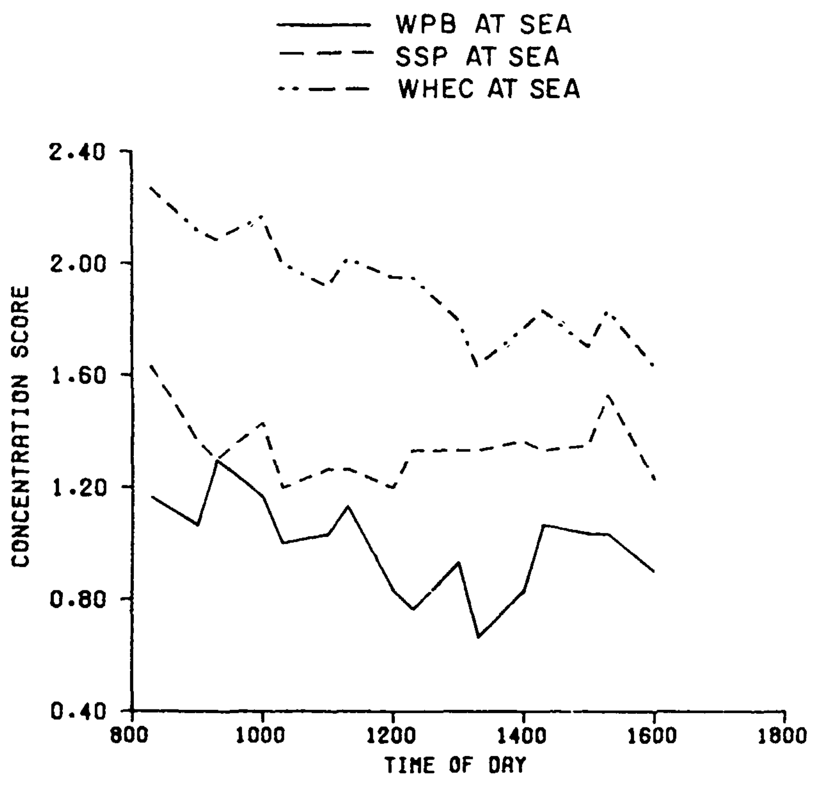


Figure 26--Average report of concentration aboard each vessel during steaming days.

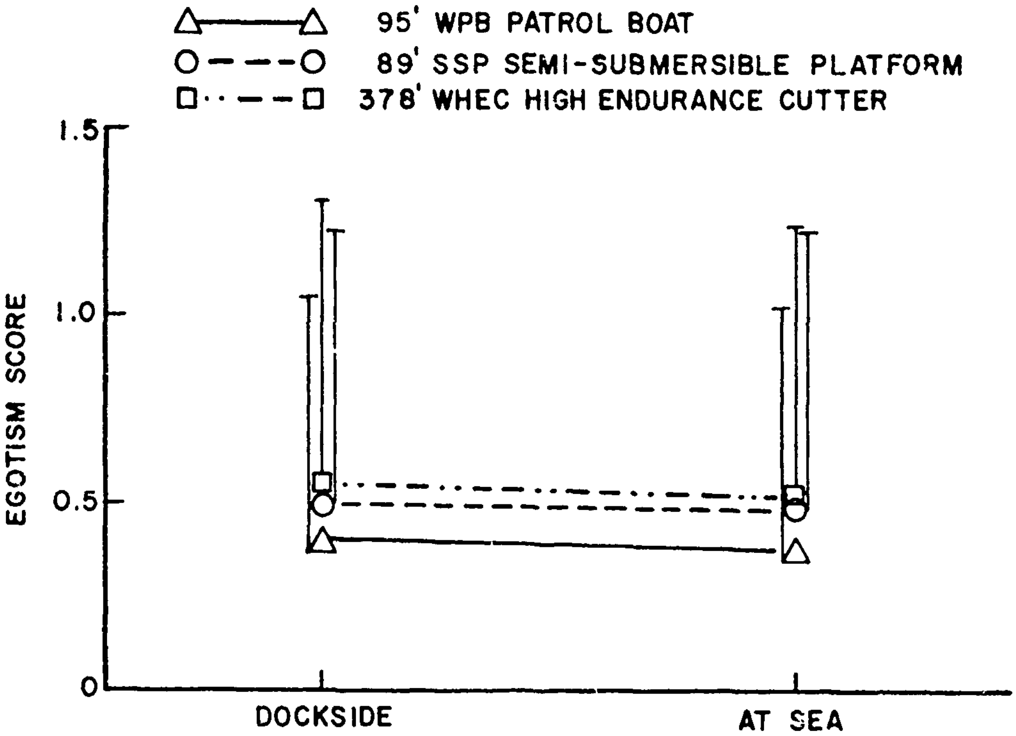


Figure 27--Mean response and standard error of egotism reports for vessel class and testing condition.

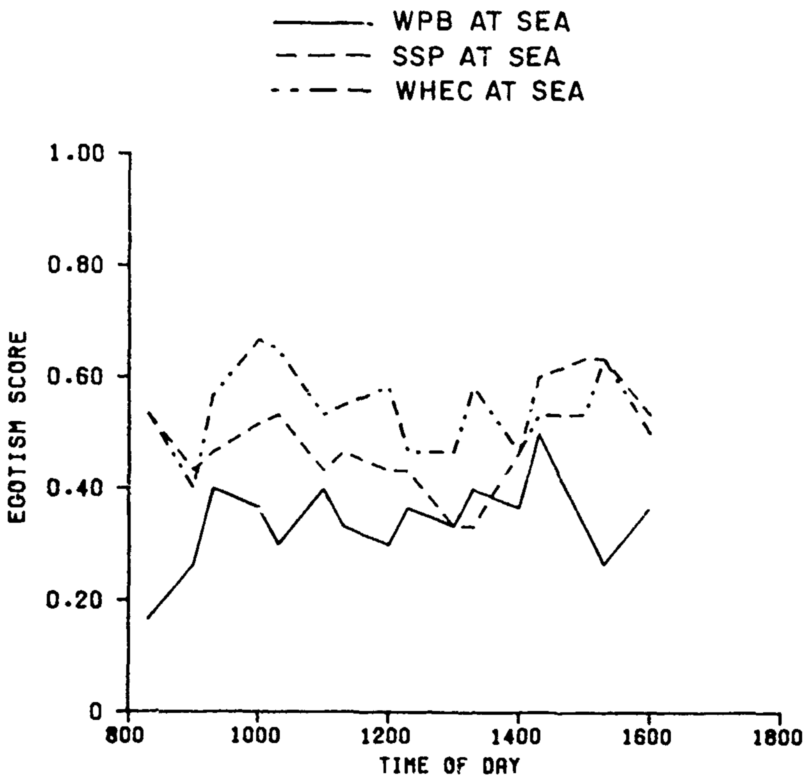


Figure 28--Average report of egotism aboard each vessel during steaming days.

day were lower than those aboard the other vessels ($p < .05$). The differences did not parallel in magnitude and direction with those found between vesseles during the dockside data collection period. See Figure 28 on the preceeding page.

Exposure to the WPB at sea led to a reduction in reports of elation from dockside levels ($p < .001$). No significant differences were found between dockside and steaming day reports obtained aboard either the SSP or WHEC. See Figure 29.

Elation scores generated from subject reports taken aboard the WPB at sea were lower than those obtained aboard the SSP or WHEC ($p < .001$). Additionally, WHEC reports of elation at sea were lower than those obtained aboard the SSP ($p < .01$). No differences were found between vessels during the dockside periods. See Figure 30.

The curves shown in Figure 31 for the SSP and WHEC are similar to those seen at dockside which on the average ranged between feelings of "definitely not" and "uncertain" levels of elation. Furthermore, most subjects, regardless of vessel, reported increases in feelings related to elation near the end of the eight hour testing period.

Reports of fatigue were unchanged from dockside and steaming conditions aboard the SSP and WHEC. Exposure to the WPB at sea, however, produced an increase in fatigue scores from "uncertain" at dockside to "slightly" at sea ($p < .001$). See Figure 31.

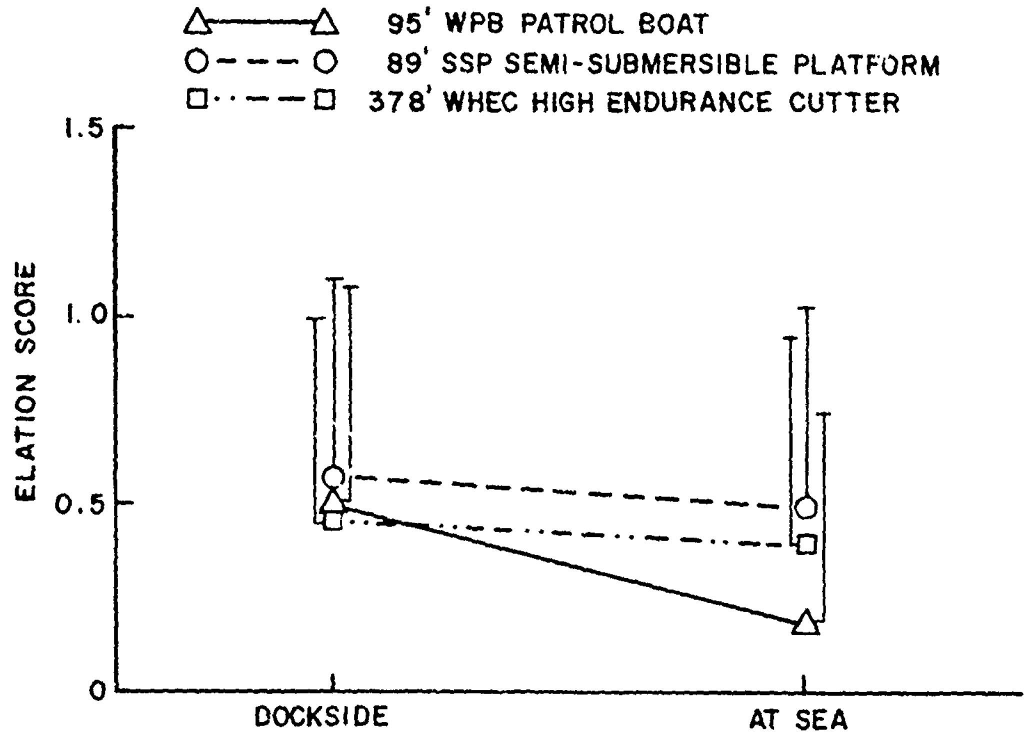


Figure 29--Mean response and standard error of elation reports for vessel class and testing condition.

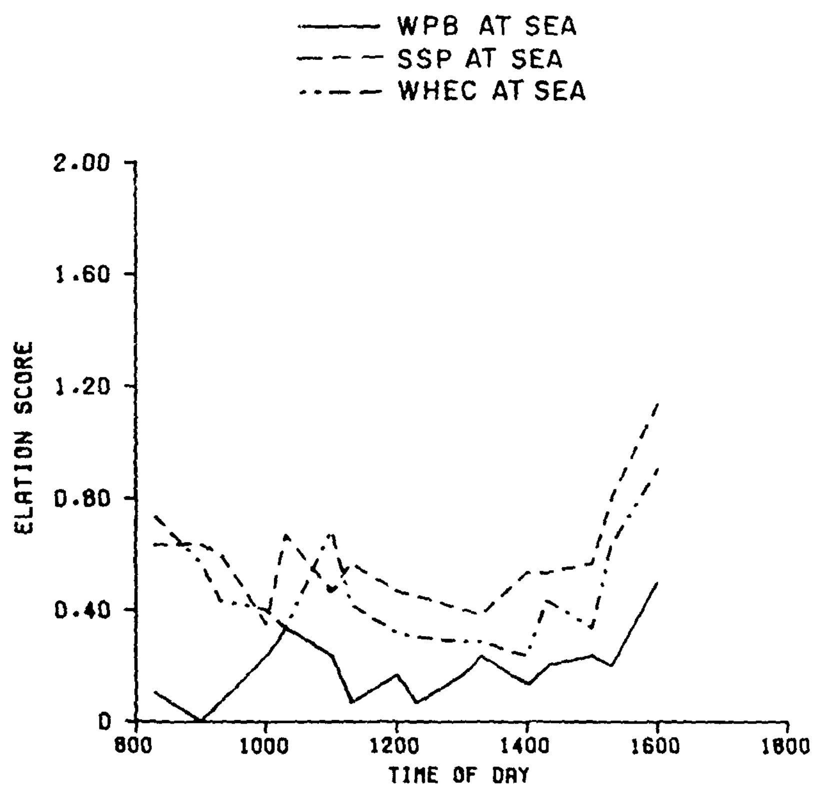


Figure 30--Average report of elation aboard each vessel during steaming days.

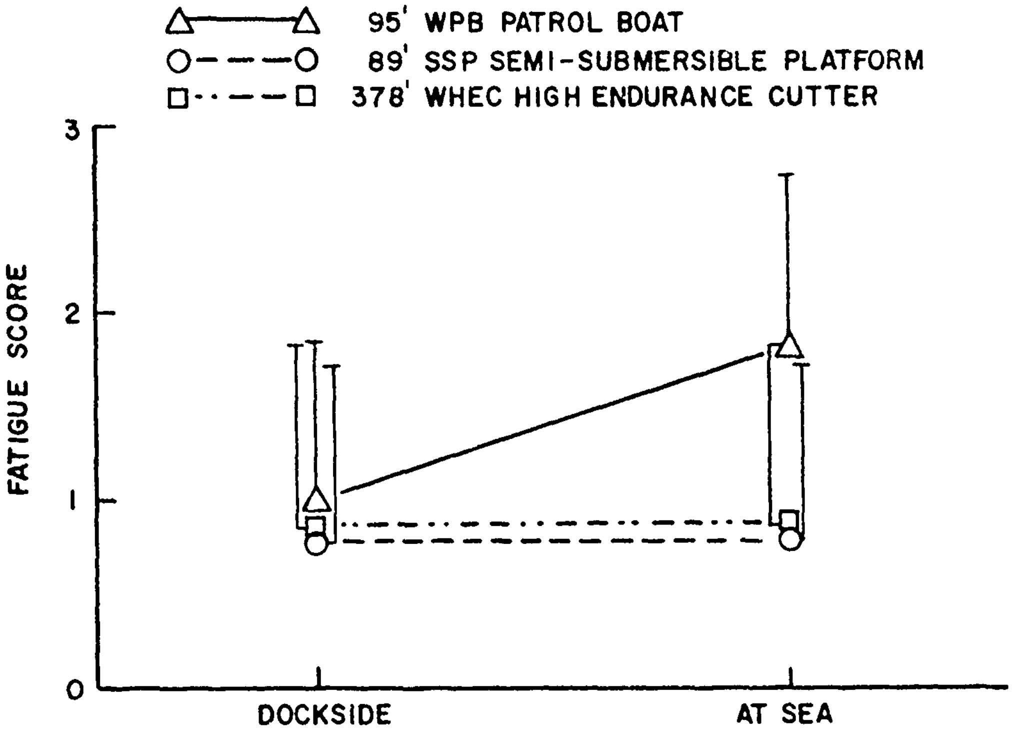


Figure 31--Mean response and standard error of fatigue reports for vessel class and testing condition.

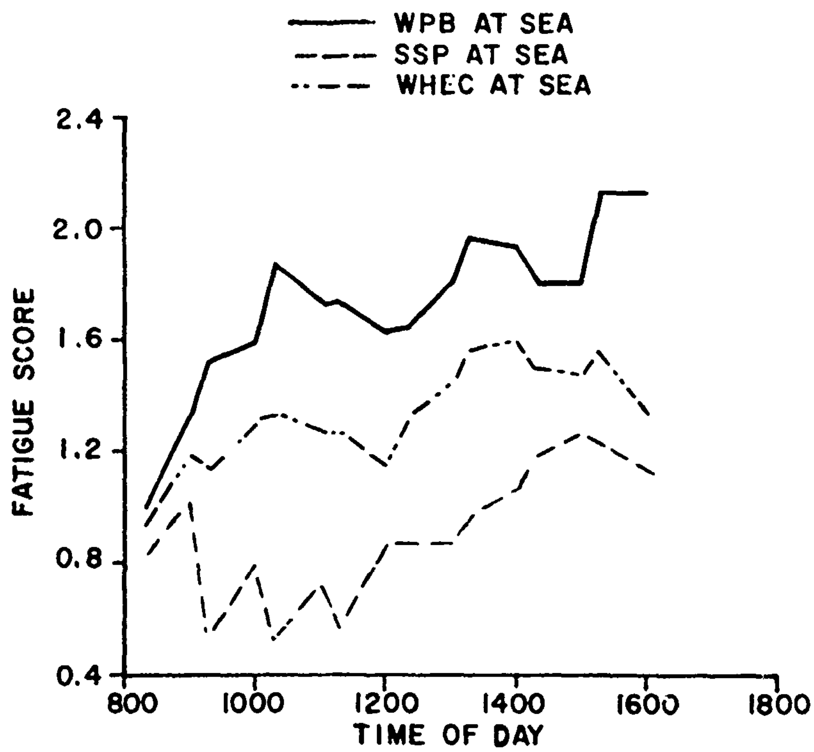


Figure 32--Average report of fatigue aboard each vessel during steaming days.

Examination of fatigue scores generated from steaming day data shows a general increase in severity of reports occurred as the day progressed. This trend was found in the dockside data as well.

Though no significant differences were found between fatigue scores aboard the vessels at dockside, significant differences in subject fatigue were found between all vessel classes at sea.

The WPB produced fatigue scores substantially greater than those obtained aboare either the SSP or WHEC at sea ($p < .001$). Reports of fatigue were also greater aboard the WHEC at sea than those aboard the SSP ($p < .01$). See Figure 32.

Subject reports of sadness did not change from dockside to steaming conditions aboard the SSP, however, increases in reports at sea were found aboard both the WHEC ($p < .01$) and WPB ($p < .001$). See Figure 33.

Though no significant differences were found in dockside levels of sadness between the WPB and SSP or between the SSP and WHEC, sadness scores aboard the WHEC were lower than those found aboard the WPB ($p < .05$) At sea comparisons showed no significant differences between the WHEC and SSP, while sadness scores aboard the WPB were greater than either of the other vessels ($p < .001$). See Figure 34.

Subject reports of skepticism remained unchanged from dockside to steaming conditions aboard all three vessels. See Figure 35.

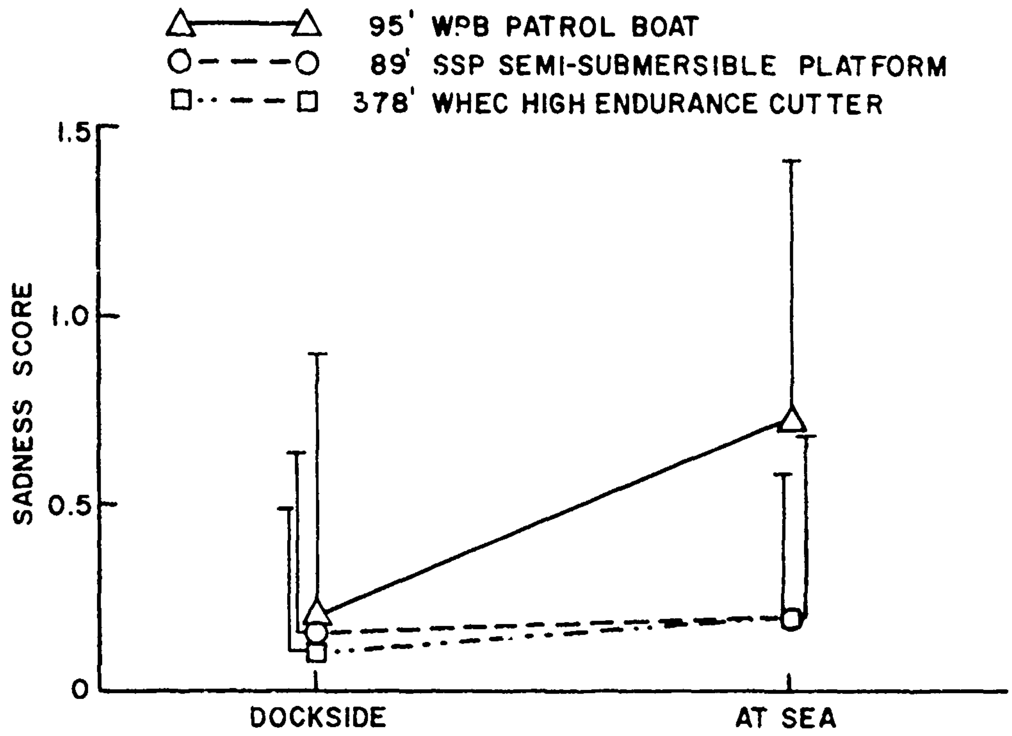


Figure 33--Mean reponse and standard error of sadness reports for vessel class and testing condition.

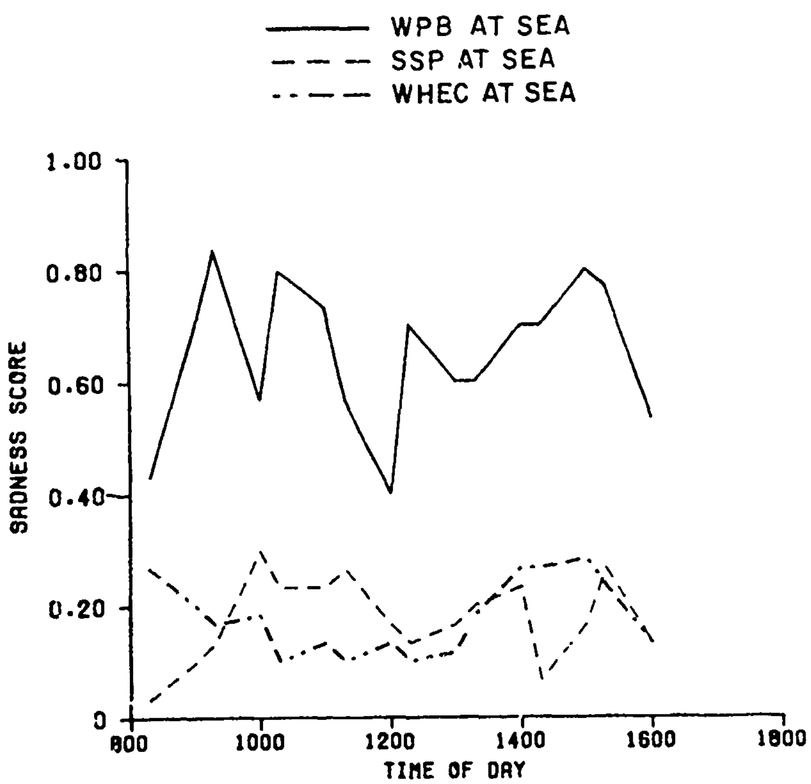


Figure 34--Average report of sadness aboard each vessel during steaming days.

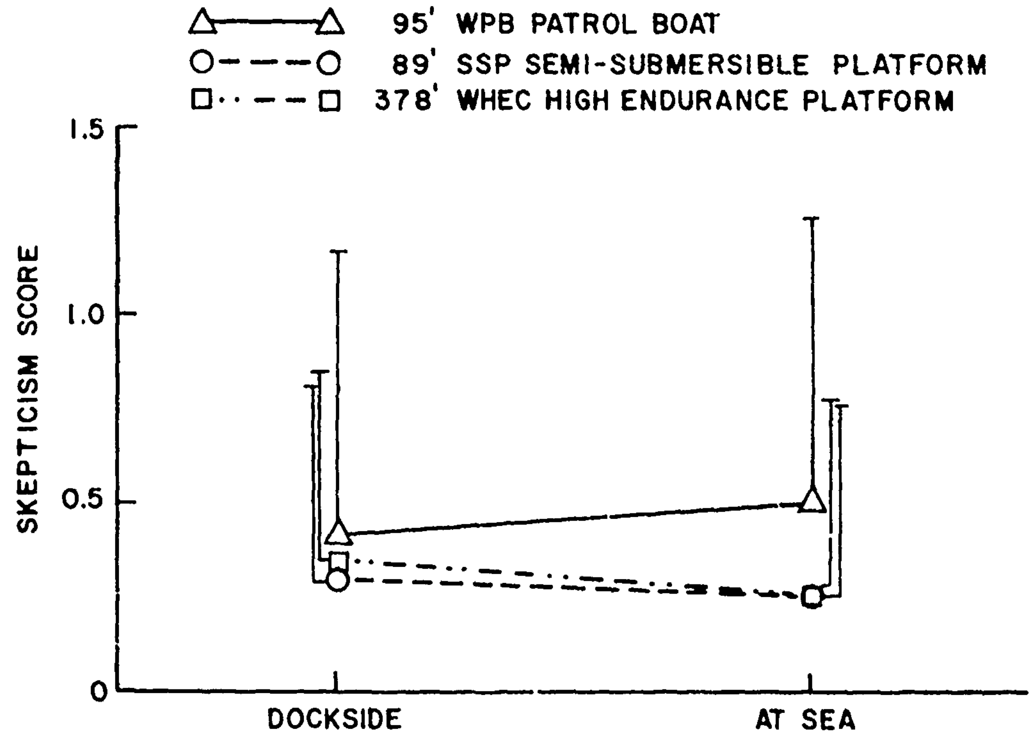


Figure 35--Mean response and standard error of skepticism reports for vessel class and testing condition.

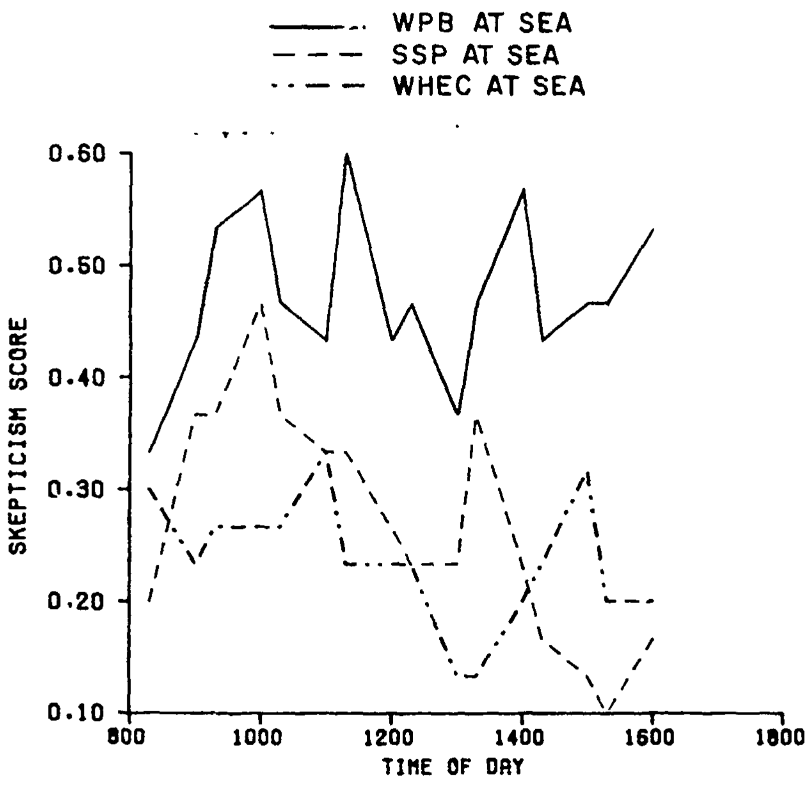


Figure 36--Average report of skepticism aboard each vessel during steaming days.

During dockside periods no differences were found between reports of skepticism aboard the SSP and WHEC. Dockside reports of skepticism aboard the WPB were slightly greater than the other vessels ($p < .01$).

At sea no differences were found between the SSP and WHEC in levels of reported skepticism while the WPB yielded higher scores ($p < .001$). The range of the shifts, or differences, in skepticism mean scores were small and varied between score categories of "definitely not" and "uncertain". See Figure 36.

Reports concerning the mood dimension of social affection were unchanged from dockside to steaming conditions aboard the SSP and WPB. Social affection scores, as shown in Figure 37, increased at sea aboard the WHEC ($p < .05$) from dockside levels.

During dockside periods aboard the WHEC subjects reported lower degrees of social affection than when aboard the other vessels ($p < .01$); however, at sea there were no differences between vessels.

As shown in Figure 38, social affection was generally lowest in the morning aboard the WPB at sea but gradually increased as the testing period progressed.

Surgency scores obtained dockside and at sea were unchanged aboard the SSP. Steaming conditions aboard the WHEC were associated with a slight increase ($p < .05$) in feelings of surgency while exposure to the WPB steaming environment led to declines from dockside levels ($p < .001$). The shifts

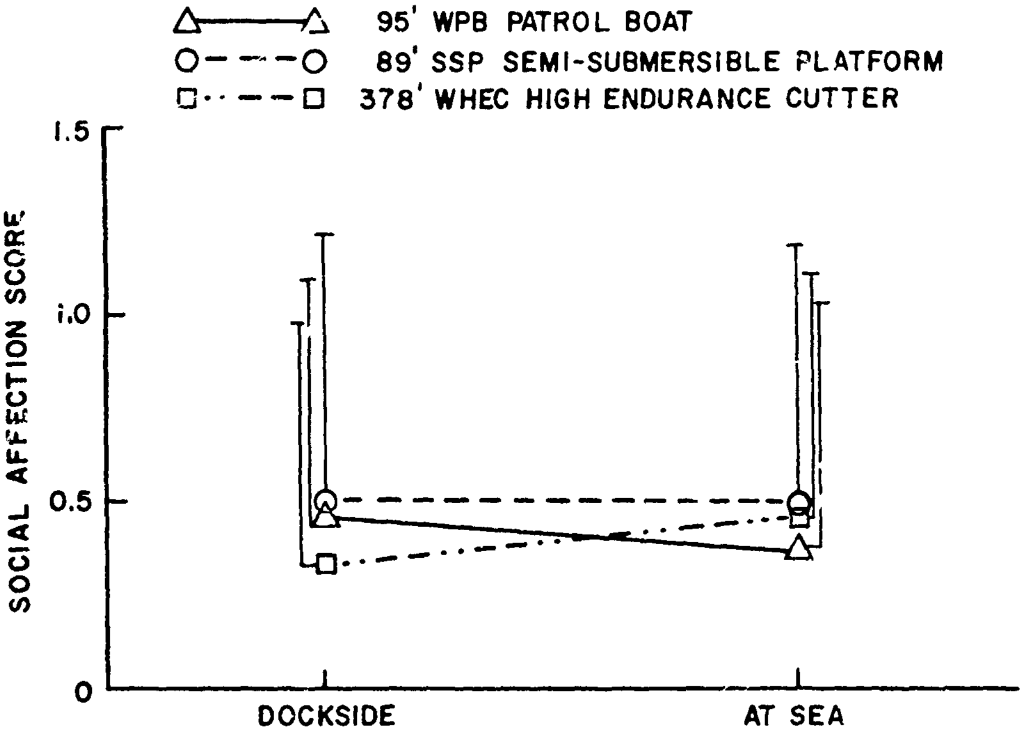


Figure 37--Mean response and standard error of social affection reports for vessel class and testing condition.

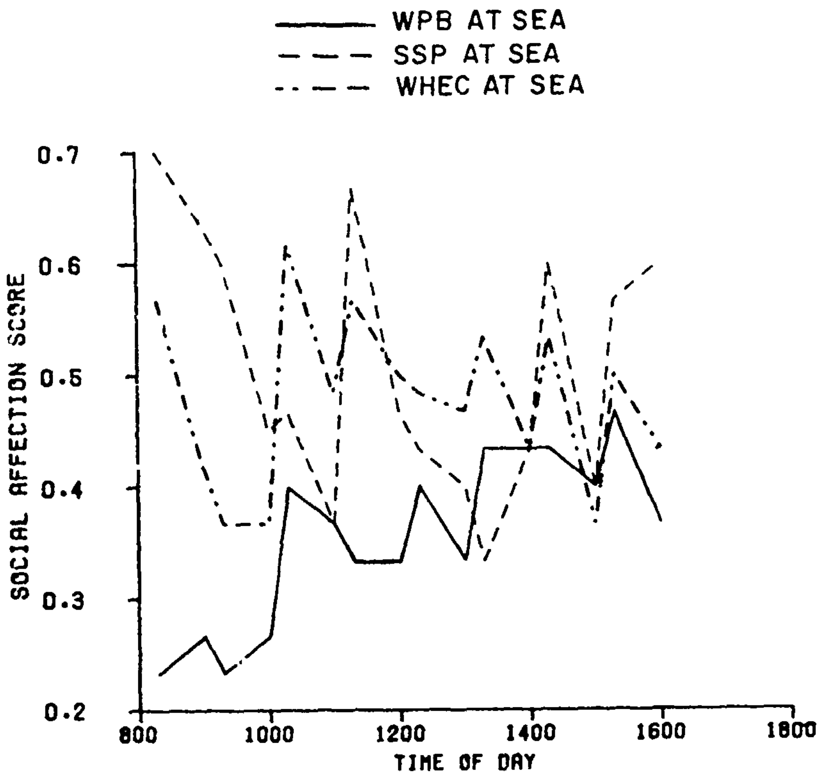


Figure 38--Average report of social affection aboard each vessel during steaming days.

in mood were relatively small and ranged on the average between "definitely not" and "uncertain" levels. See Figure 39.

Dockside reports concerning surgency were equivalent across vessels. No differences were found between reports aboard the SSP and WHEC at sea. Comparison of steaming day surgency scores obtained aboard the WPB showed the scores to be lower than either the SSP or WHEC ($p < .001$). See Figure 40.

A reduction in reported vigor was found aboard the WPB at sea when compared to dockside levels ($p < .001$). No significant changes in vigor were reported between dockside and steaming day testing conditions aboard either the SSP or WHEC. See Figure 41.

No significant differences were found between vessels with vigor scores obtained during dockside testing periods. Scores of vigor were equivalent at sea aboard the SSP and WHEC. Scores obtained from subjects exposed to the WPB at sea were lower those obtained aboard the SSP and WHEC ($p < .001$).

As shown in Figure 41 subjects were generally uncertain about the degree of vigor they felt aboard the SSP and WHEC at sea. Yet when the subjects were aboard the WPB at sea they reported they were definitely not feeling "active", "energetic" or "vigorous".

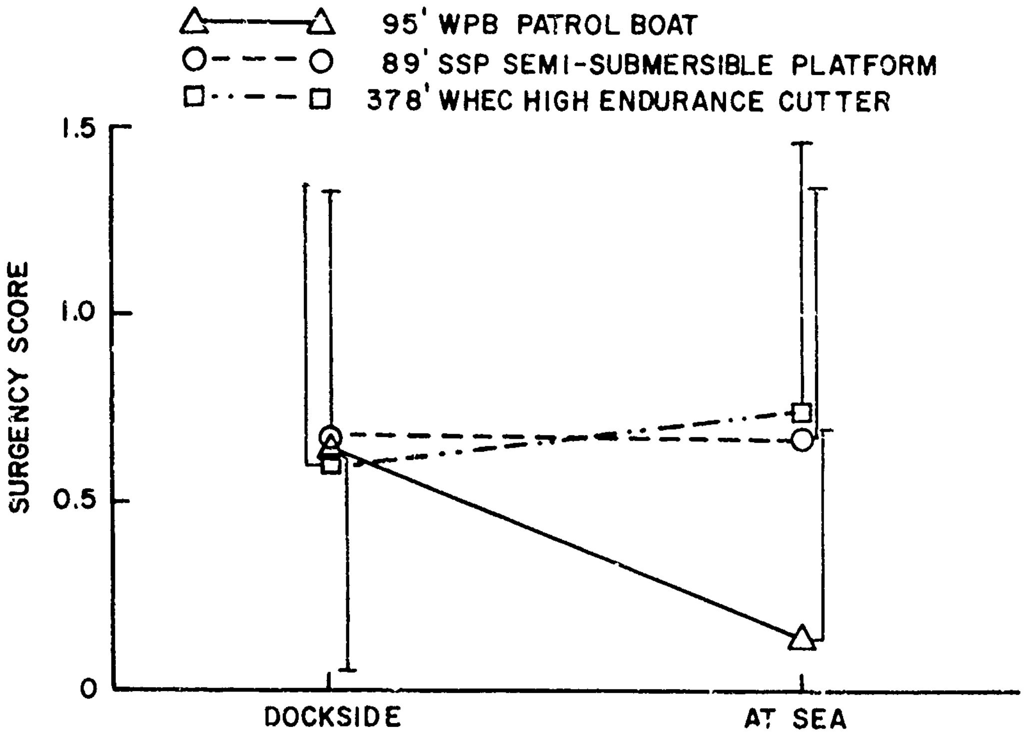


Figure 39--Mean response and standard error of surgency reports for vessel class and testing condition.

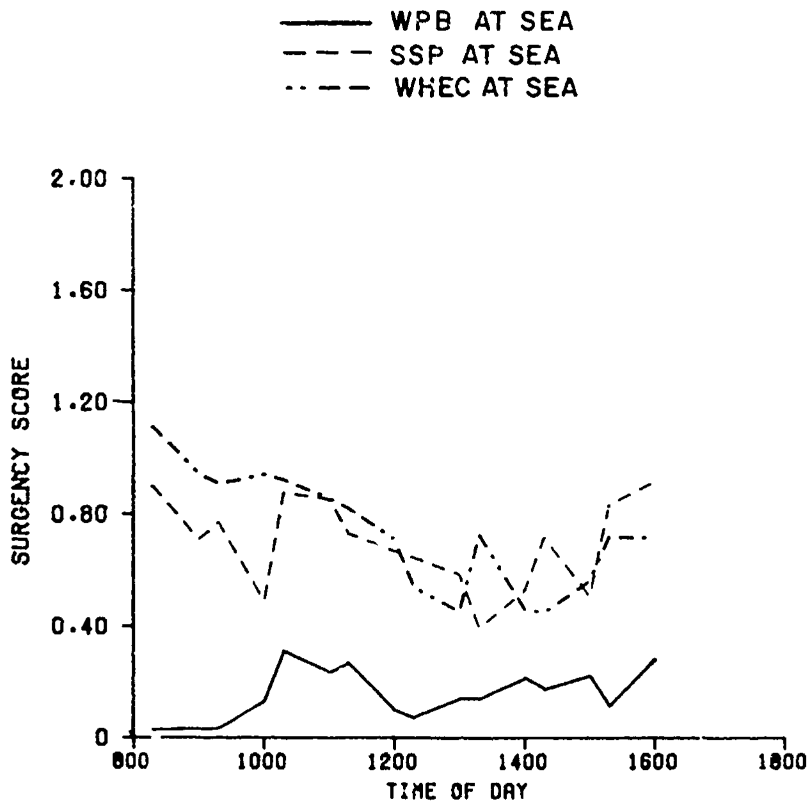


Figure 40--Average report of surgency aboard each vessel during steaming days.

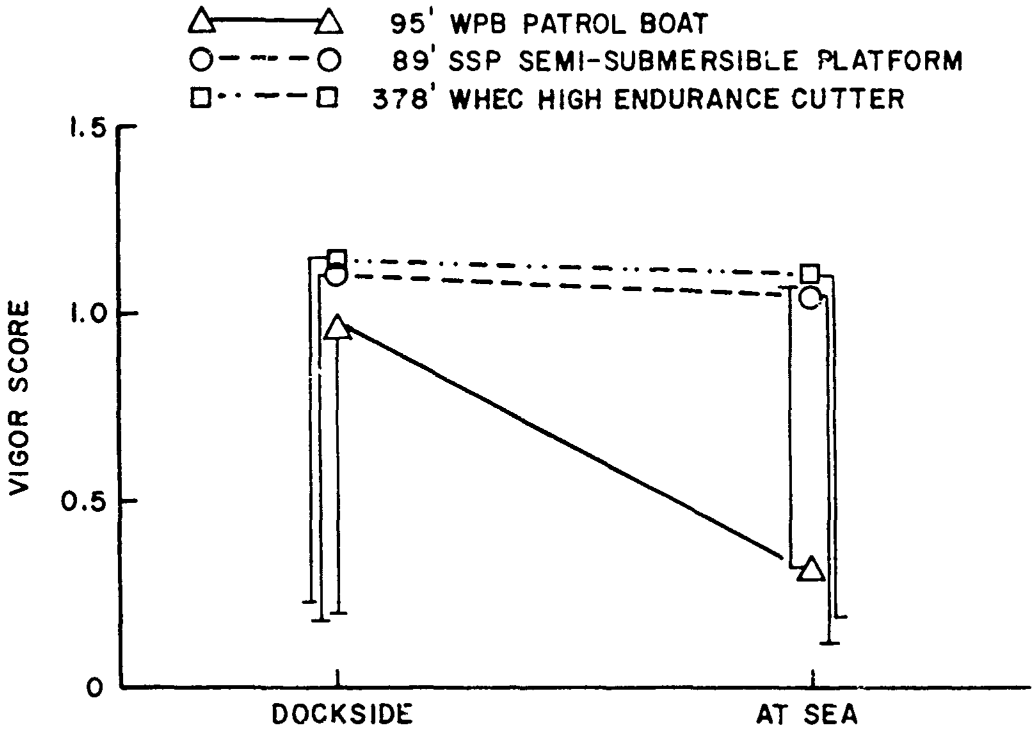


Figure 41--Mean response and standard error of vigor reports for vessel class and testing condition.

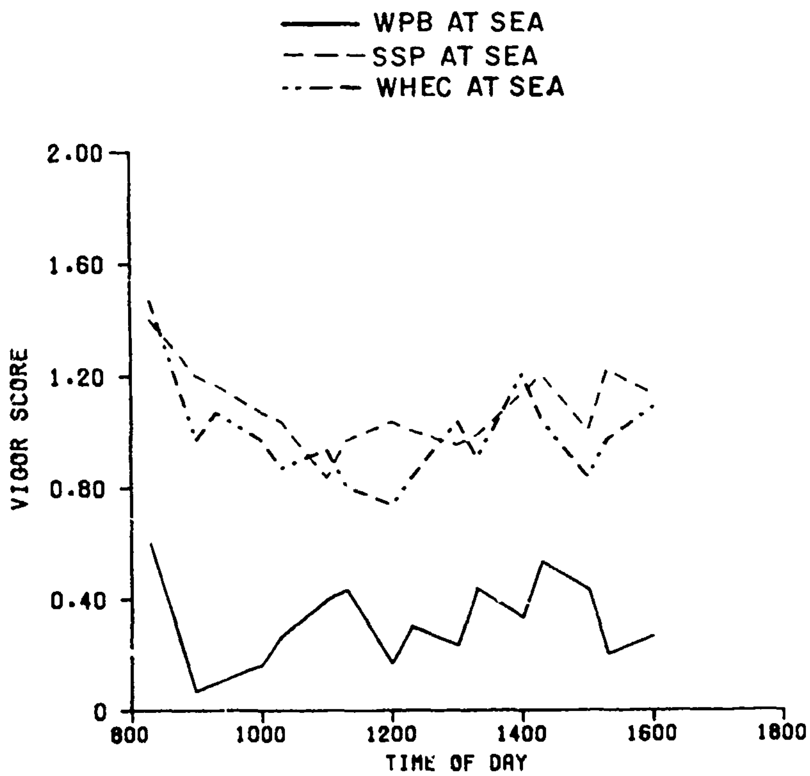


Figure 42--Average report of vigor aboard each vessel during steaming days.

Vessel Class Differences in Performance

Test subject task performance was examined for within vessel class differences between dockside and at-sea conditions and for between vessel class differences at sea using the dichotomous variable regression analysis technique described earlier. The results of thoses analyses are summarized in Tables 13, 14, 15, and 16.

As shown in Figure 43 the average number of code substitutions completed did not change significantly between dockside and steaming conditions aboard the SSP or WHEC. Steaming day conditions aboard the WPB, however, led to a decline in the number of alpha-numeric substitutions completed ($\overline{\Delta}$= 15.1%, $p < .001$) when compared to dockside performance levels.

The number of code substitutions made at sea were less when subjects were aboard the WPB when compared to either the SSP or WHEC ($p < .001$). Although the number of substitutions completed generally declined throughout the day aboard all vessels at sea, subjects when aboard the WPB performed on the average 13.0% fewer substitutions than when aboard either the SSP or WHEC. There were no differences in code substitution performance levels between the SSP and WHEC at sea. See Figure 44.

Complex counting performance was scored using the percentage of low tone quartets accurately counted. Previous experiments in which all three tones were scored showed equivalency in error rates across tones (Kennedy, 1979) and, given the sequence of tone presentation, the low tones were the most convenient to score.

Table 13--Comparisons between dockside and at-sea means for performance measures taken aboard the SSP.

Measure	Dockside $\bar{x} \pm SE$	At-Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitutition (Attempts)	84.5 ± 15.6	85.1 ± 15.6	.00	Treatment	31	1	31	0.1
				Residual	64619	264	245	
Complex Counting (% Correct)	36.8 ± 24.5	38.6 ± 24.5	.00	Treatment	45	1	45	0.1
				Residual	142259	237	600.3	
Critical Tracking (λ_c)	5.0 ± 2.4	4.9 ± 2.4	.01	Treatment	72	1	72	2.1
				Residual	9182	264	35	
Navigation Plotting (Attempts)	25.4 ± 6.7	26.5 ± 6.7	.01	Treatment	75	1	75	1.7
				Residual	11536	258	45	
Navigation Plotting (# Correct)	19.0 ± 5.5	19.5 ± 5.5	.00	Treatment	15	1	15	0.5
				Residual	7888	258	30.6	
Spoke Test Control Time (Sec)	29.7 ± 4.0	30.4 ± 4.0	.01	Treatment	37	1	37	2.3
				Residual	4224	264	16	
Spoke Test Experimental Time (sec)	105.4 ± 18.8	101.1 ± 18.8	.01	Treatment	1214	1	1214	3.4*
				Residual	93946	264	355.9	
Spoke Test Difference Time (Sec)	75.7 ± 17.9	70.7 ± 17.9	.02	Treatment	1674	1	1674	5.3*
				Residual	84197	264	318.9	
Time Estimation (12 sec. interval)	10.0 ± 0.1	9.9 ± 0.1	.01	Treatment	0.009	1	0.009	1.3
				Residual	1.657	240	0.0069	

* $p < .05$
** $p < .01$
*** $p < .001$

Table 14--Comparisons between dockside and at-sea means for performance measures taken aboard the WPB.

Measure	Dockside $\bar{x} \pm SE$	At-Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitution (Attempts)	86.3 ± 16.7	73.3 ± 16.7	0.13	Treatment Residual	10991 71466	1 257	10991 278	39.5***
Complex Counting (% Correct)	46.9 ± 23.4	33.2 ± 23.4	0.07	Treatment Residual	110057 1277466	1 233	110057 5483	20.1***
Critical Tracking (λ_c)	4.9 ± 2.5	4.1 ± 2.5	0.24	Treatment Residual	3080 9648	1 246	3080 39	78.9***
Navigation Plotting (Attempts)	26.1 ± 7.1	20.6 ± 7.1	0.13	Treatment Residual	1958 12791	1 252	1958 50.8	38.6***
Navigation Plotting	19.4 ± 5.9	15.6 ± 5.9	0.09	Treatment Residual	909 8820	1 252	909 35	25.9***
Spoke Test Control Time (Sec)	29.5 ± 5.1	33.0 ± 5.1	0.11	Treatment Residual	783 6638	1 257	783 25.8	30.3***
Spoke Test Experimental Time (Sec)	104.1 ± 20.1	112.5 ± 20.1	0.04	Treatment Residual	4097 102811	1 254	4097 404.8	10.1***
Spoke Test Difference Time (Sec)	75.1 ± 18.8	79.8 ± 18.8	0.02	Treatment Residual	1427 90333	1 254	1427 255.6	4.0*
Time Estimate (12 sec. period)	11.4 ± .12	10.9 ± .12	0.02	Treatment Residual	0.028 1.49	1 223	0.028 0.007	4.2*

* $p < .05$
** $p < .01$
*** $p < .001$

Table 15--Comparisons between dockside and at-sea means for performance measures taken aboard the WHEC.

Measure	Dockside $\bar{x} \pm SE$	At Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitution (Attempts)	83.0 ± 14.4	84.6 ± 14.4	0.003	Treatment Residual	180 55188	1 265	180 208.3	0.9
Complex Counting (% Correct)	46.4 ± 25.8	43.9 ± 25.8	0.002	Treatment Residual	3519 1564257	1 234	3519 6685	0.5
Critical Tracking (λ_c)	4.8 ± 2.4	4.9 ± 2.4	0.002	Treatment Residual	18 9016	1 265	18 34	0.5
Navigation Plotting (Attempts)	24.3 ± 6.3	26.9 ± 6.3	0.04	Treatment Residual	432 10180	1 259	432 39.3	10.9***
Navigation Plotting (# Correct)	18.2 ± 5.3	20.3 ± 5.3	0.04	Treatment Residual	299 7379	1 259	299 28.5	10.5***
Spoke Test Control Time (Sec)	29.9 ± 3.8	28.8 ± 3.8	0.02	Treatment Residual	77 3736	1 265	77 14.1	5.5*
Spoke Test Experimental Time (Sec)	104.1 ± 18.8	98.8 ± 18.8	0.02	Treatment Residual	1868 93387	1 265	1868 352	5.3*
Spoke Test Difference Time (Sec)	74.2 ± 18.6	70.0 ± 18.6	0.01	Treatment Residual	1185 92119	1 265	1185 348	3.4
Time Estimation (12 sec. period)	10.4 ± 0.1	10.9 ± .01	0.02	Treatment Residual	0.036 2.293	1 253	0.036 0.009	4.0*

* $p < .05$
** $p < .01$
*** $p < .001$

Table 16--Comparisons between vessel class means for performance task data collected at-sea.

Measure	SSP $\bar{x} \pm SE$	WPB $\bar{x} \pm SE$	WHEC $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
Code Substitution (Attempts)	85.1 ± 16.2	73.3 ± 16.2	84.6 ± 16.2	0.10	Treatment Residual	11771 103935	1 398	5885.6 261.2	22.5***
Complex Counting (% Correct)	38.7 ± 24.9	33.2 ± 24.9	43.9 ± 24.9	0.03	Treatment Residual	727157 23592514	1 381	363578 61922	5.9**
Critical Tracking (λ_c)	4.6 ± 2.4	4.1 ± 2.4	5.0 ± 2.4	0.23	Treatment Residual	4303 14510	2 406	2151.5 35.7	60.3***
Navigation Plotting (Attempts)	26.5 ± 6.9	20.7 ± 6.9	26.9 ± 6.9	0.14	Treatment Residual	3064 18205	2 381	1532 47.8	32.06***
Navigation Plotting (# Correct)	19.5 ± 5.7	15.6 ± 5.7	20.3 ± 5.7	0.12	Treatment Residual	1598 12206	2 381	799 32.1	24.9***
Spoke Test Control Time (Sec)	30.4 ± 4.7	33.0 ± 4.7	28.8 ± 4.7	0.12	Treatment Residual	1188 8790	2 398	594.0 22.1	26.9***
Spoke Test mental Time (Sec)	101.1 ± 19.3	112.5 ± 19.3	98.9 ± 19.3	0.09	Treatment Residual	14005 146619	2 395	7002.6 371.2	18.9***
Spoke Test Difference Time (Sec)	70.7 ± 18.1	79.7 ± 18.1	70.0 ± 18.1	0.06	Treatment Residual	7614 129729	2 395	3807 328.4	11.6***
Time Estimation (12 sec period)	10.0 ± 0.1	11.9 ± 0.1	10.6 ± 0.1	0.05	Treatment Residual	0.182 3.220	2 370	0.091 0.009	10.5***

* $p < .05$
** $p < .01$
*** $p < .001$

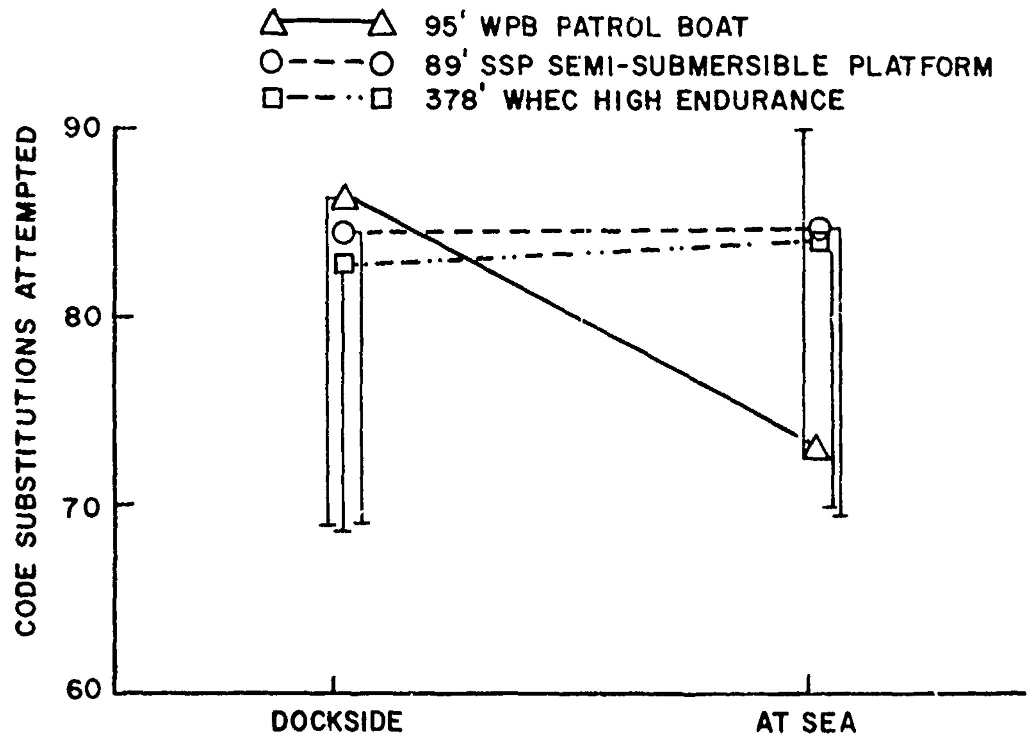


Figure 43--Mean response and standard error of code substitutions made for vessel class and testing condition.

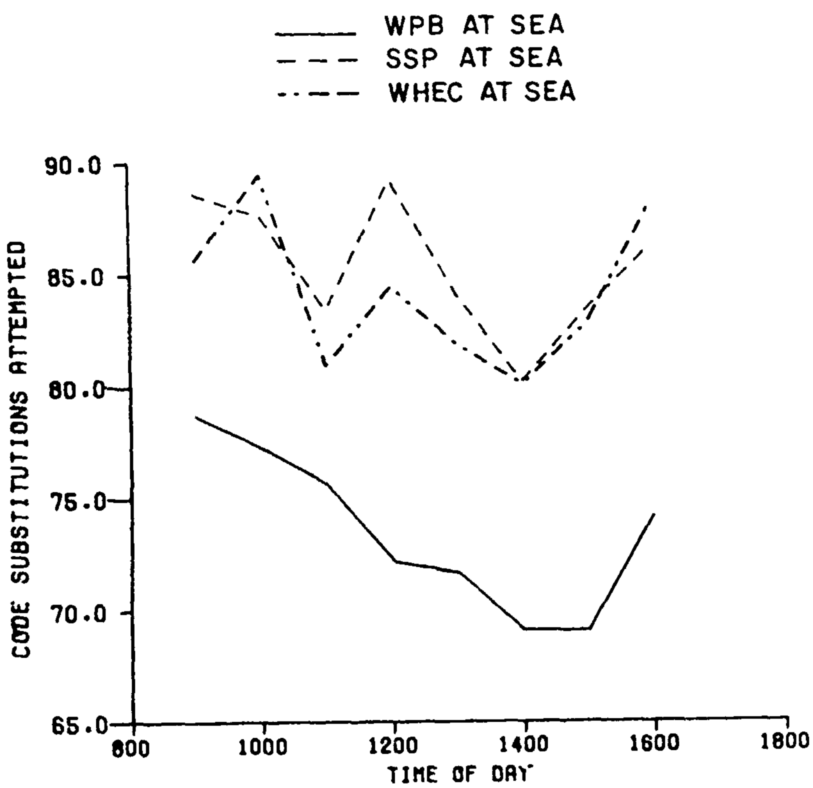


Figure 44--Average code substitution performance aboard each vessel during steaming days.

Analysis of complex counting test scores showed performance remained unchanged between dockside and steaming conditions aboard the SSP and WHEC. An average reduction of 29.2% ($p < .001$) in low tone counting accuracy occurred from dockside to steaming day exposures aboard the WPB. See Figure 45.

No significant differences were found in complex counting performance between vessels at dockside. When at sea comparisons were made, however, WPB exposures led to less accurate performance than that seen aboard either the SSP or WHEC; 14.3% ($p < .01$) lower than the SSP and 24.4% ($p < .01$) lower than WHEC scores obtained at sea. No significant differences were found in complex counting performance between the SSP and WHEC at sea. See Figure 46.

Critical tracking task performance remained unchanged from dockside levels aboard the SSP and WHEC at sea. The median of five runs each trial showed the compensatory tracking bandwidth limit (λ_c) to be reduced for subjects when exposed to the WPB during steaming days ($\overline{\Delta}$ =16.3%, $p < .001$). See Figure 47.

Tracking performance, when compared across vessels at sea, showed differences in performance levels between all vessels. The best tracking performance was found aboard the WHEC with scores aboard the SSP only slightly poorer ($\overline{\Delta}$ = 8.0%, $p < .05$). The worst performance was found aboard the WPB which produced tracking scores averaging 10.9% ($p < .05$) lower than those generated aboard the SSP and 18.0% ($p < .001$) lower than WHEC scores. See Figure 48.

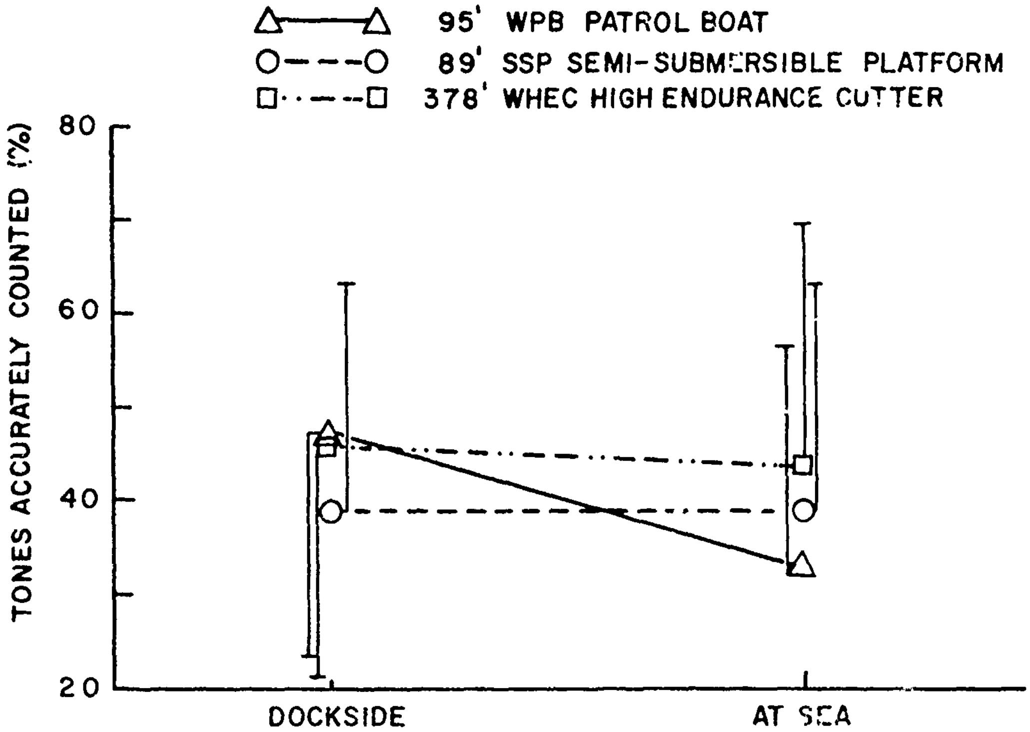


Figure 45--Mean response and standard error of complex counting scores for vessel class and testing condition.

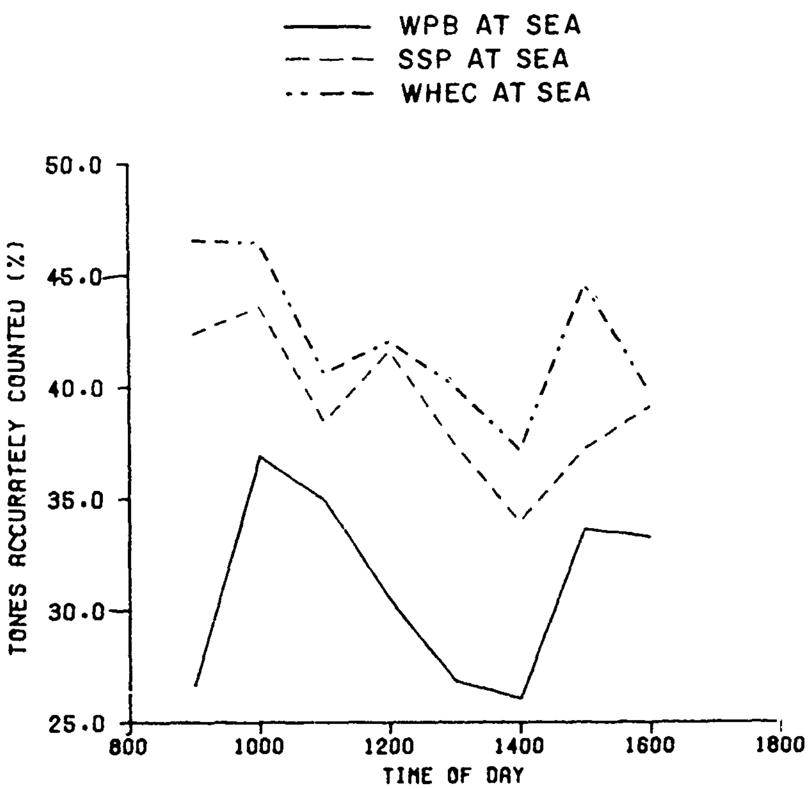


Figure 46--Average complex counting performance aboard each vessel during steaming days.

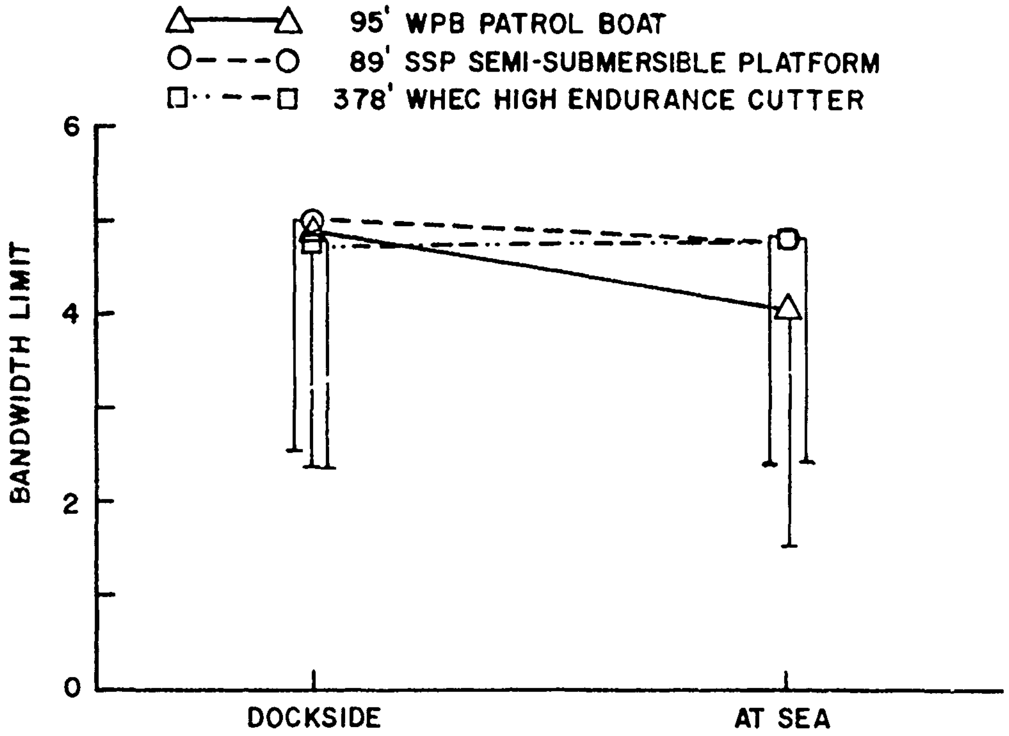


Figure 47--Mean response and standard error of critical tracking performance for vessel class and testing condition.

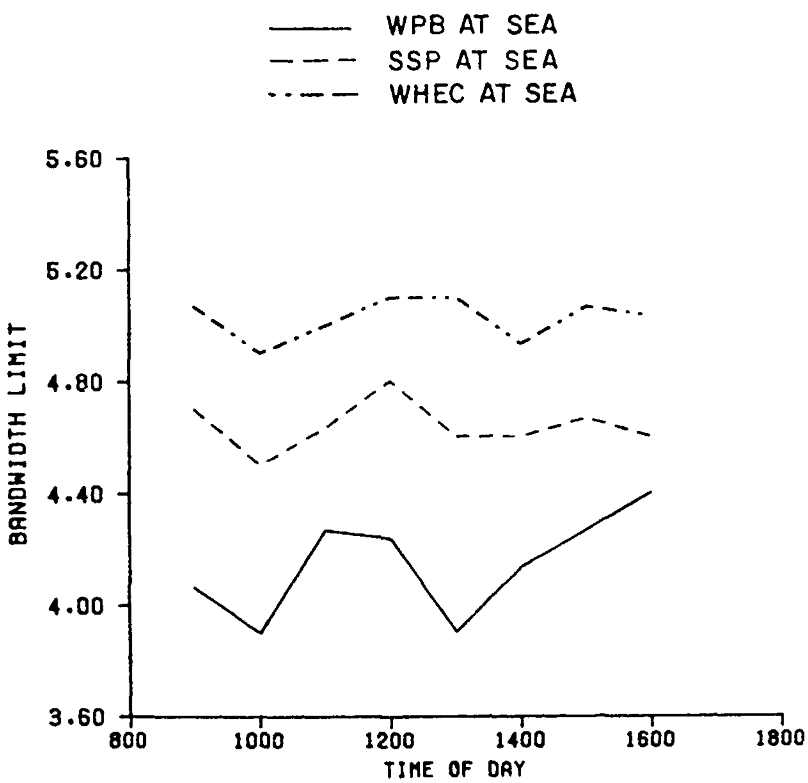


Figure 48--Average critical tracking task score aboard each vessel during steaming days.

While no signficant decrements were found in the number of navigation plotting problems attempted between dockside and steaming conditions aboard the SSP and WHEC, an average reduction of 21.1% ($p < .001$) was found in the number of navigation plotting problems completed aboard the WPB at sea.

The WHEC scores showed an improvement in navigation plotting performance from dockside to steaming conditions ($\bar{\Delta}$ = 10.7%, $p < .05$). The SSP exhibited improvements at sea as well, however, statistical significance was not acheived. See Figure 49.

Comparing the number of navigation plotting problems attempted across vessels at sea showed there were no significant differences between the SSP and WHEC. The number of problems attempted aboard the WPB were on the average over 20.0% ($p < .001$) less than scores obtained from either of the other vessels. No significant differences were found between vessels during dockside testing periods. See Figure 50

The number of correct navigation plotting solutions provided aboard the SSP were equivalent between dockside and steaming conditions. Similar comparisons showed the number of correct navigation plotting solutions increased while at sea aboard the WHEC ($\bar{\Delta}$ = 11.5%, $p < .001$) and decreased when subjects were exposed to the WPB ($\bar{\Delta}$ = 19.6%, $p < .001$)

It should be noted that the percentage of correct solutions provided did not change from dockside to steaming conditions aboard any vessel.

Fewer correct navigation plotting solutions were obtained aboard the WPB at sea when compared to the equivalent accuracy scores obtained aboard the SSP ($\bar{\Delta}$ = 20.0%, $p < .001$) or WHEC ($\bar{\Delta}$ = 23.3%, $p < .001$).

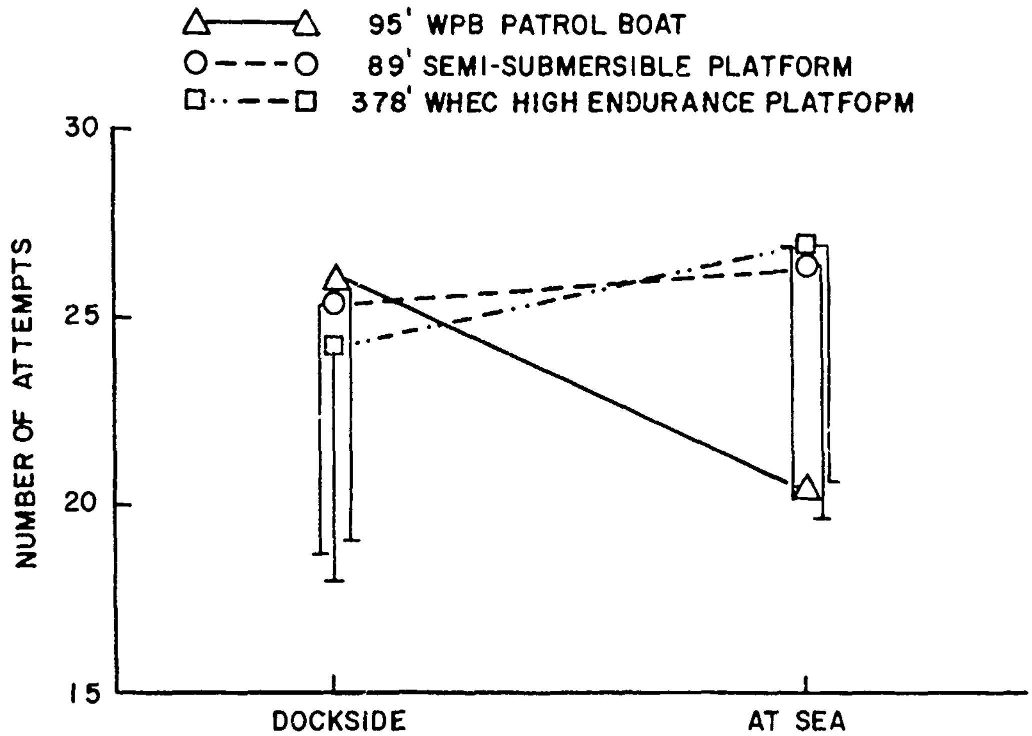


Figure 49--Mean response and standard error of navigation plotting problems attempted for vessel class and testing condition.

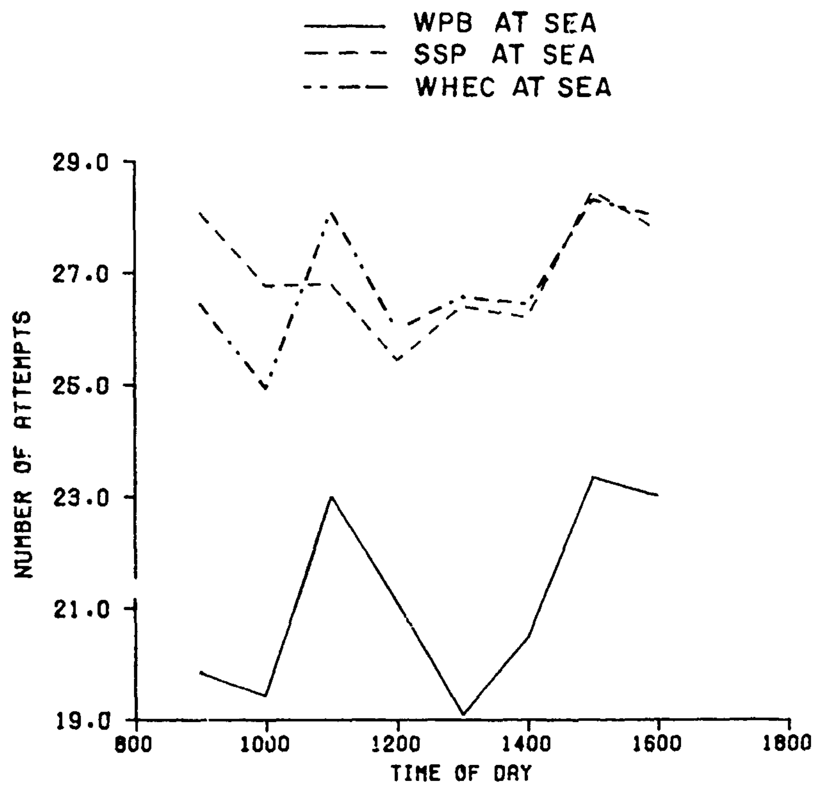


Figure 50--Average number of navigation plotting problems attempted aboard each vessel during steaming days.

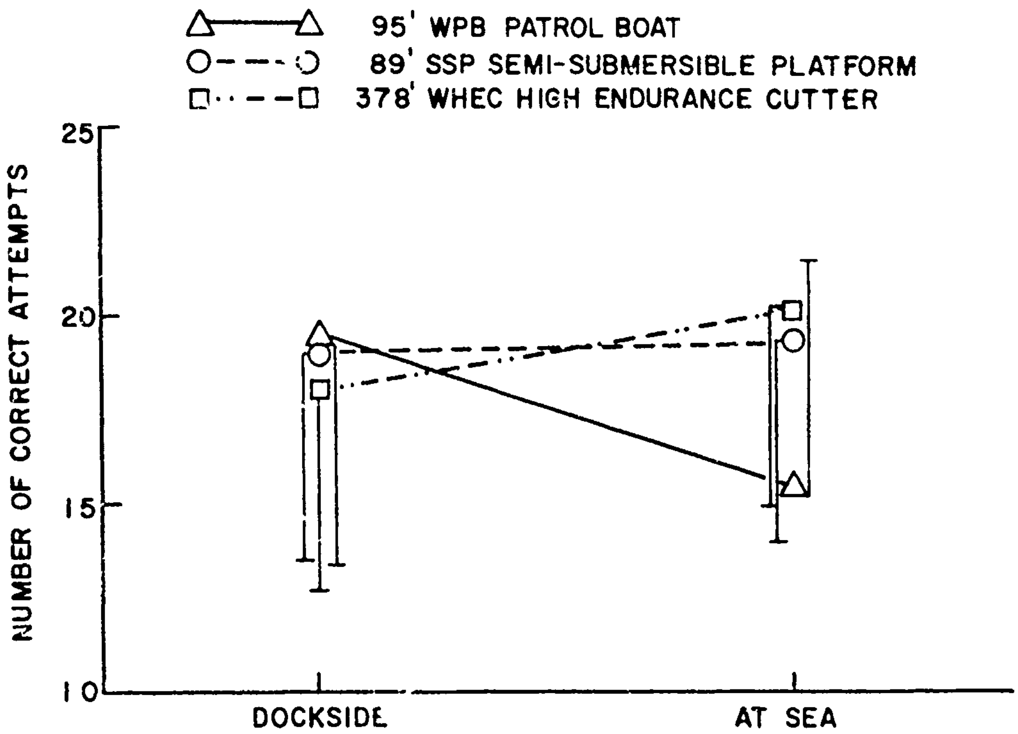


Figure 51--Mean response and standard error of correct attempts at navigation plotting problems for vessel class and testing condition.

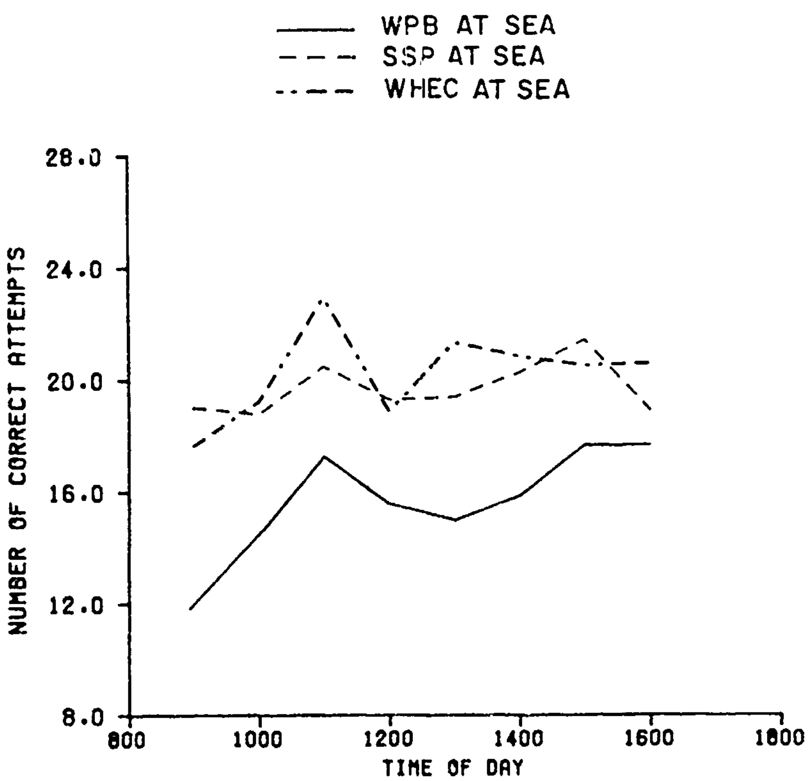


Figure 52--Average number of correct attempts of navigation plotting problems aboard each vessel during steaming days.

Completion times for the Spoke Test (control) task remained unchanged from dockside to steaming conditions aboard the SSP and WHEC. The reaction and movement times associated with the tapping task were increased aboard the WPB at sea when compared to dockside values ($\overline{\Delta} = 11.9\%$, $p < .001$). See Figure 53.

Spoke Test (control) completion times were longer aboard the WPB at sea than either the SSP ($\overline{\Delta} = 8.6\%$, $p < .01$) or WHEC ($\overline{\Delta} = 14.8\%$, $p < .01$) times. Furthermore, times to complete the simple tapping task were longer aboard the SSP at sea than those found aboard the WHEC ($\overline{\Delta} = 5.6\%$, $p < .01$). See Figure 54.

Time to complete both the tapping and visual search components of the Spoke Test (experimental) decreased at sea aboard both the SSP ($\overline{\Delta} = 4.1\%$, $p < .05$) and WHEC ($\overline{\Delta} = 5.1\%$, $p < .05$). Exposure to the WPB during steaming periods led to an increase in task completion times from those recorded at dockside ($\overline{\Delta} = 8.1\%$, $p < .001$). See Figure 55.

Completion times for the Spoke Test (experimental) trials were longer aboard the WPB at sea than either the SSP ($\overline{\Delta} = 11.3\%$, $p < .01$) or the WHEC ($\overline{\Delta} = 13.9\%$, $p < .01$). No significant differences were found between the SSP and WHEC times at sea or between all vessels during dockside test periods. See Figure 56.

Subtraction of the simple tapping task (Spoke Test (control)) completion times from those of the Spoke Test (experimental) data yielded a difference score which seperated the processing time from the manual aspects of the task. The difference scores, or processing times, decreased aboard the SSP from

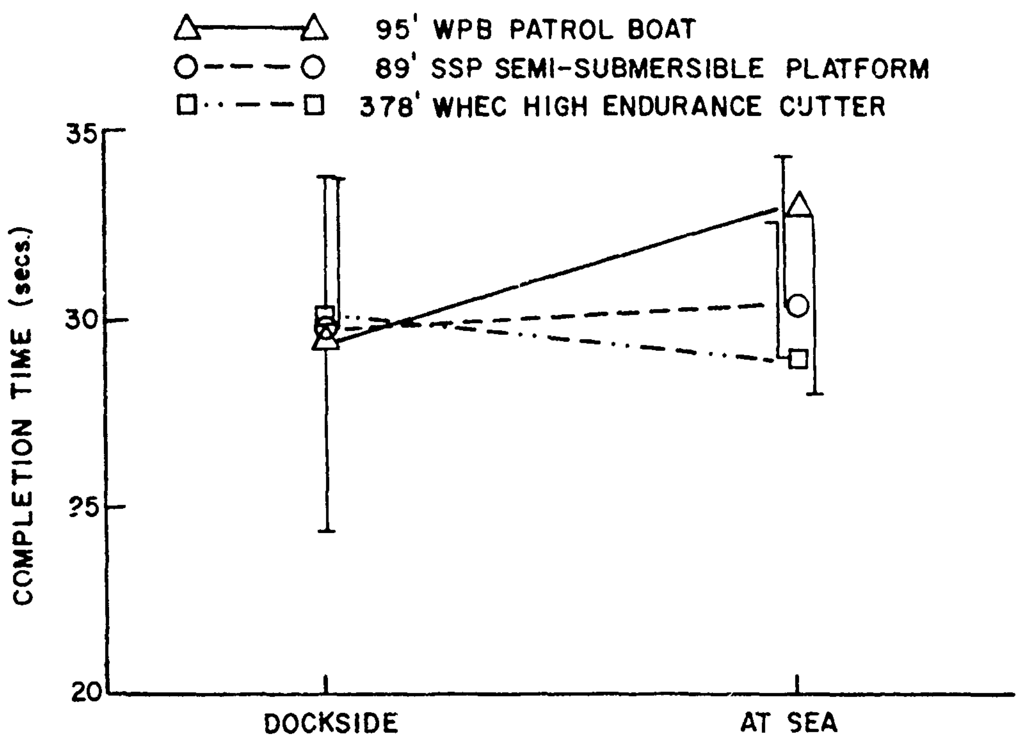


Figure 53--Mean response and standard error of Spoke Test (control) times for vessel class and testing condition.

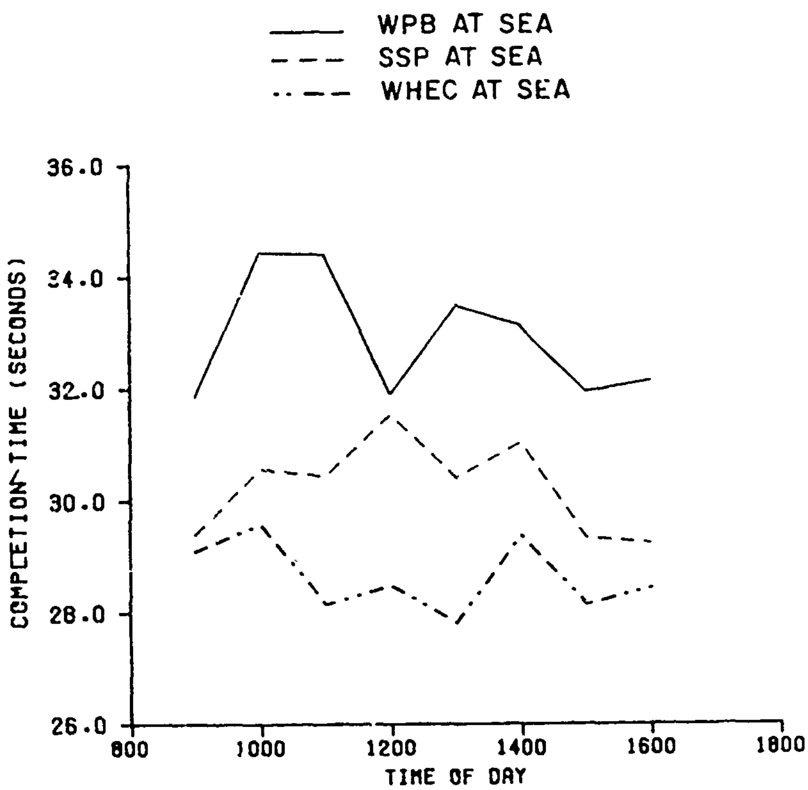


Figure 54--Average Spoke Test (control) performance aboard each vessel during steaming days.

dockside levels by an average of 6.6% ($p < .05$). No significant change was found in difference times aboard the WHEC while WPB exposures during steaming days led to increases in difference times ($\overline{\Delta} = 6.3\%$, $p < .05$). See Figure 57.

Spoke Test (difference) times were not significantly different between vessels at dockside or between the SSP and WHEC at sea. WPB difference scores at sea were greater than those found aboard the SSP ($\overline{\Delta} = 12.7\%$, $p < .001$) and WHEC ($\overline{\Delta} = 13.9\%$, $p < .001$). See Figure 58.

Comparisons of test subject estimates of twelve-second time intervals between dockside and steaming environments aboard the three vessels shows a reduction in the absolute error in estimates occurred aboard the WPB at sea ($p < .05$) while subjects aboard the WHEC at sea exhibited an increase in error from dockside estimates ($p < .05$) No changes in estimates were found between dockside and steaming periods aboard the SSP. See Figure 59.

Subjects' estimates of the twelve-second interval were different between all vessels at sea. Absolute errors were greatest aboard the SSP which yielded the shortest estimates. Interval estimates were longest aboard the WPB, with intermediate estimates found aboard the WHEC. It should be noted, however, that during dockside periods exposures to the SSP and WHEC produced shorter estimates than those obtained aboard the WPB ($p < .05$).

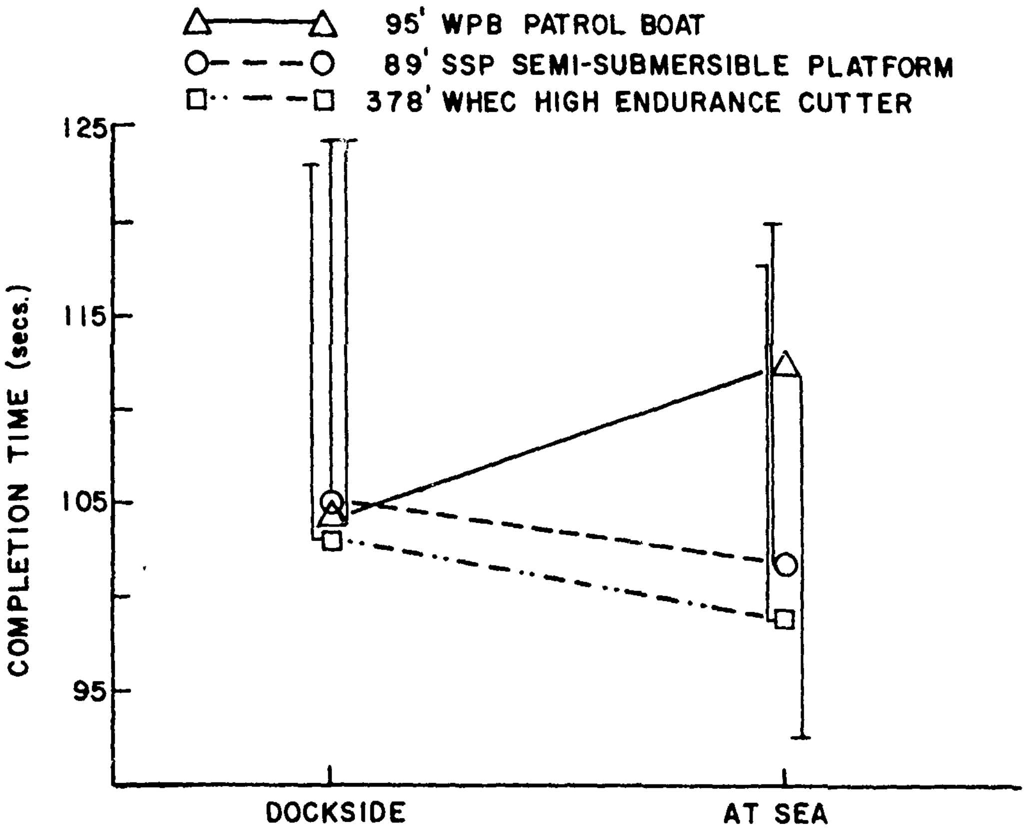


Figure 55--Mean response and standard error of Spoke Test (experimental) times for vessel class and testing condition.

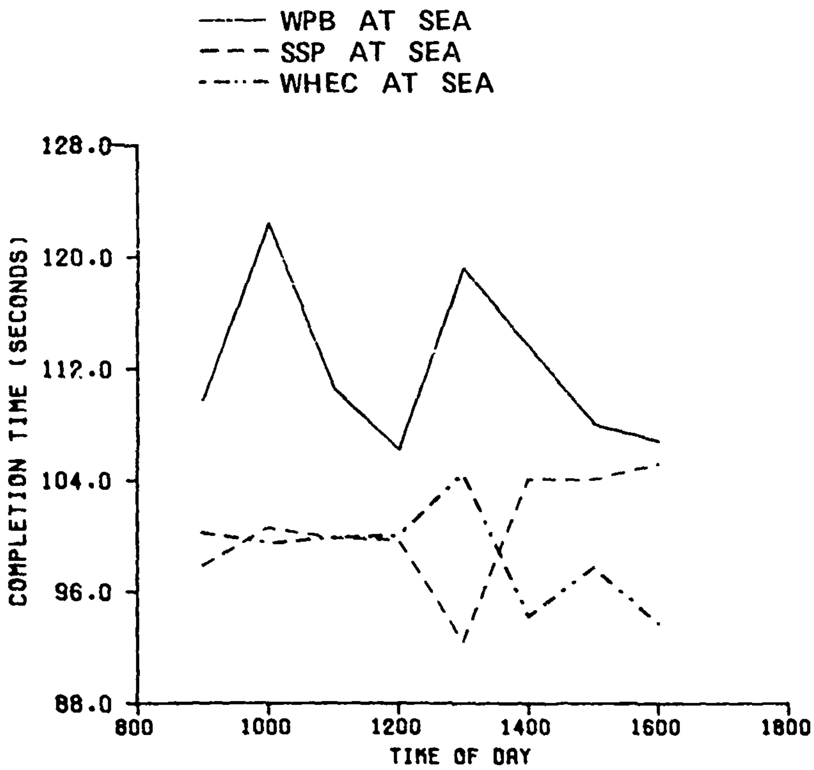


Figure 56--Average Spoke Test (experimental) completion times aboard each vessel during steaming days.

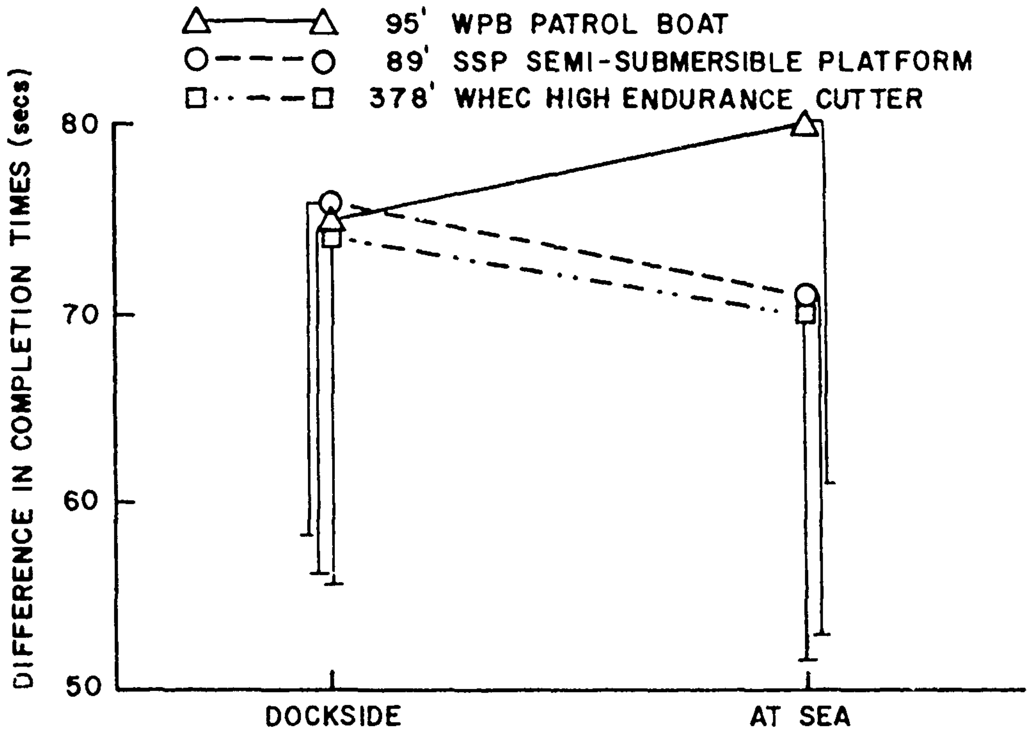


Figure 57--Mean response and standard error of Spoke Test (difference) times for vessel class and testing condition.

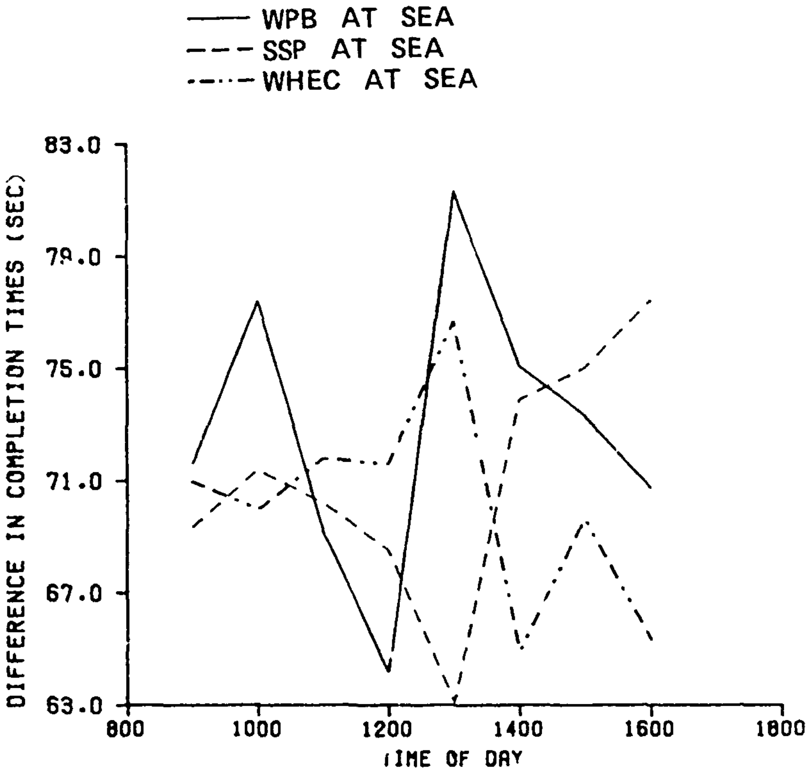


Figure 58--Average Spoke Test (difference) times aboard each vessel during steaming days.

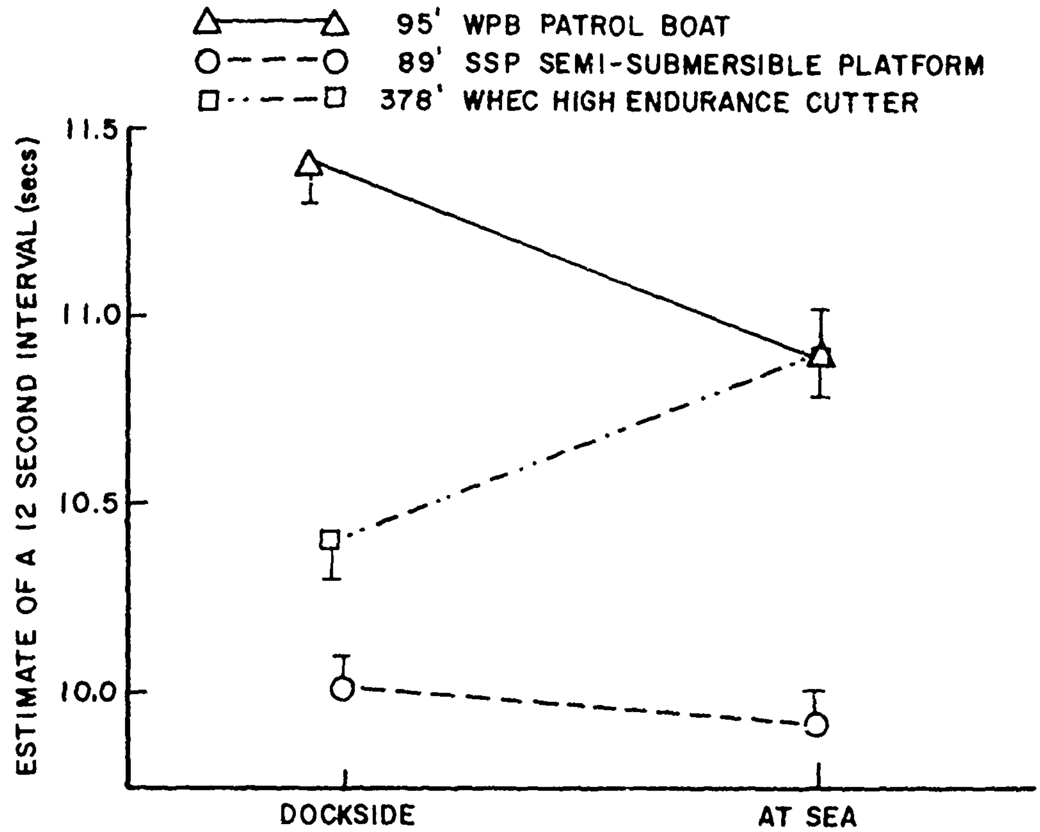


Figure 59--Mean response and standard error of time estimates for vessel class and testing condition.

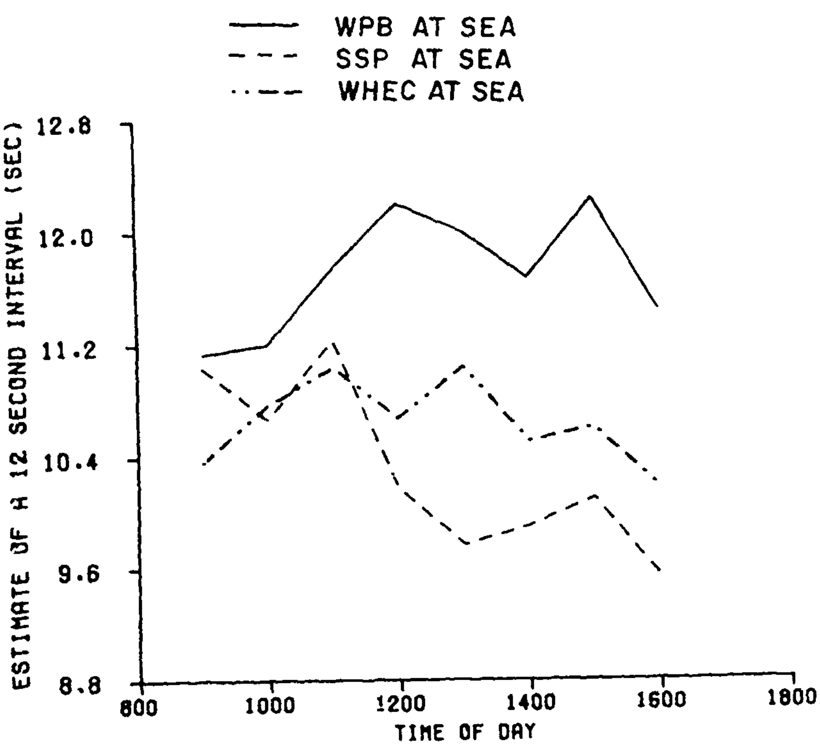


Figure 60--Average estimates of a 12-second interval aboard each vessel during steaming days.

Vessel Motion or Motion Sickness Influences

The following analyses were restricted to data obtained aboard the WPB because the WPB was the only vessel to experience performance task decrements, substantial mood shifts, and major physiological changes from dockside to steaming conditions.

A Pearson product moment correlation analysis was conducted using individual daily means during dockside and steaming days aboard the WPB to determine possible relationships between changes in independent and dependent measures from dockside to steaming conditions. Daily means were employed because of differences in sampling schedules and the need for statistical independence.

Given the large number of variables used in the correlation analysis and the magnitude of statistically significant correlations obtained, a principal components factor analysis was performed on a subset of correlations, using an orthogonal quartimax rotation, to assist in the interpretation of correlation results. All angular and heave motion measures were excluded from the factor analysis because those motion records were made just outside the WPB testing compartment, and their inclusion prevented successful inversion of the correlation matrix.

Following the results obtained from correlation and factor analyses, multiple regression analyses were performed

on hourly data for descriptive rather than for predictive purposes. Motion sickness symptomatology severity scores obtained every thirty minutes were regressed against vessel motion measures and other independent variables such as test compartment temperature, humidity, length of exposure and exposure day in an effort to determine quantitative and qualitative contributions of each predictor to motion sickness genesis.

Upon establishing those independent variables which were significant contributors to the motion sickness syndrome, motion sickness itself was used as a predictor in the outcome of other dependent variables believed to be motion sickness dependent. In other words, urine output data were regressed against MSSS scores, and independent variables not found to be significantly related to motion sickness, to determine relative contributions to observed urine output changes during steaming days.

Correlation and Factor Analysis Results

Table 17 provides the results obtained from intercorrelation analysis of physiological measures taken aboard the WPB during dockside and steaming days. Inspection of the correlations obtained showed that motion sickness was not associated with mean heart rate or sweat rate changes. Reduction in

TABLE 17 -- Correlation matrix of physiological measures taken aboard the WPB.

	MSSS	Urine Output	Urine Sp. Grav.	Catechol-amine	17-OHCS	Heart Rate	Sweat Rate
Motion Sickness Symptomatology Severity Score (MSSS)	1						
Urine Output	-.63**	1					
Urine Specific Gravity	-.60**	-.91**	1				
Urinary Catecholamine Excretion Rate	.35*	-.23	.31	1			
Urinary 17-OHCS Excretion Rate	.75**	-.35*	.41**	.18	1		
Heart Rate	-.12	.06	-.09	-.12	-.23	1	
Sweat Rate	-.04	-.09	.17	.12	-.10	.22	1

*$p < .05$
**$p < .01$

(n = 34)

urine output and elevations in urine specific gravities, urinary excretion rates of 17-OHCS and catecholamines were significantly correlated with increased motion sickness severity.

Reductions in urine output were associated with increased urine specific gravity and increased excretion of 17-OHCS.

Although no significant correlation was found between daily mean heart rates during each twenty-five minute testing cycle and associated MSSS scores, examination of minute to minute data revealed that heart rates were significantly affected by the act of emesis. Figure 61 shows that heart rates began to rise, on the average, three minutes prior to emesis. They remained elevated during the emesis period and subsided to basal rates about six to seven minutes following the initiation of the emesis episode. Of the forty-four single emesis episodes analyzed (closely repeated episodes of emesis or periods of retching were excluded from analysis to give a clearer picture of pre and post emesis heart rate changes), the average increase in minute heart rate during emesis was 19.7% ($p < .01$). Though there were considerable among subject ($n = 16$) differences in heart rates, the general pattern described in Figure 61 was found in all forty-four episodes examined.

Correlations computed between dockside and steaming day individual means of physiological indices and WPB test

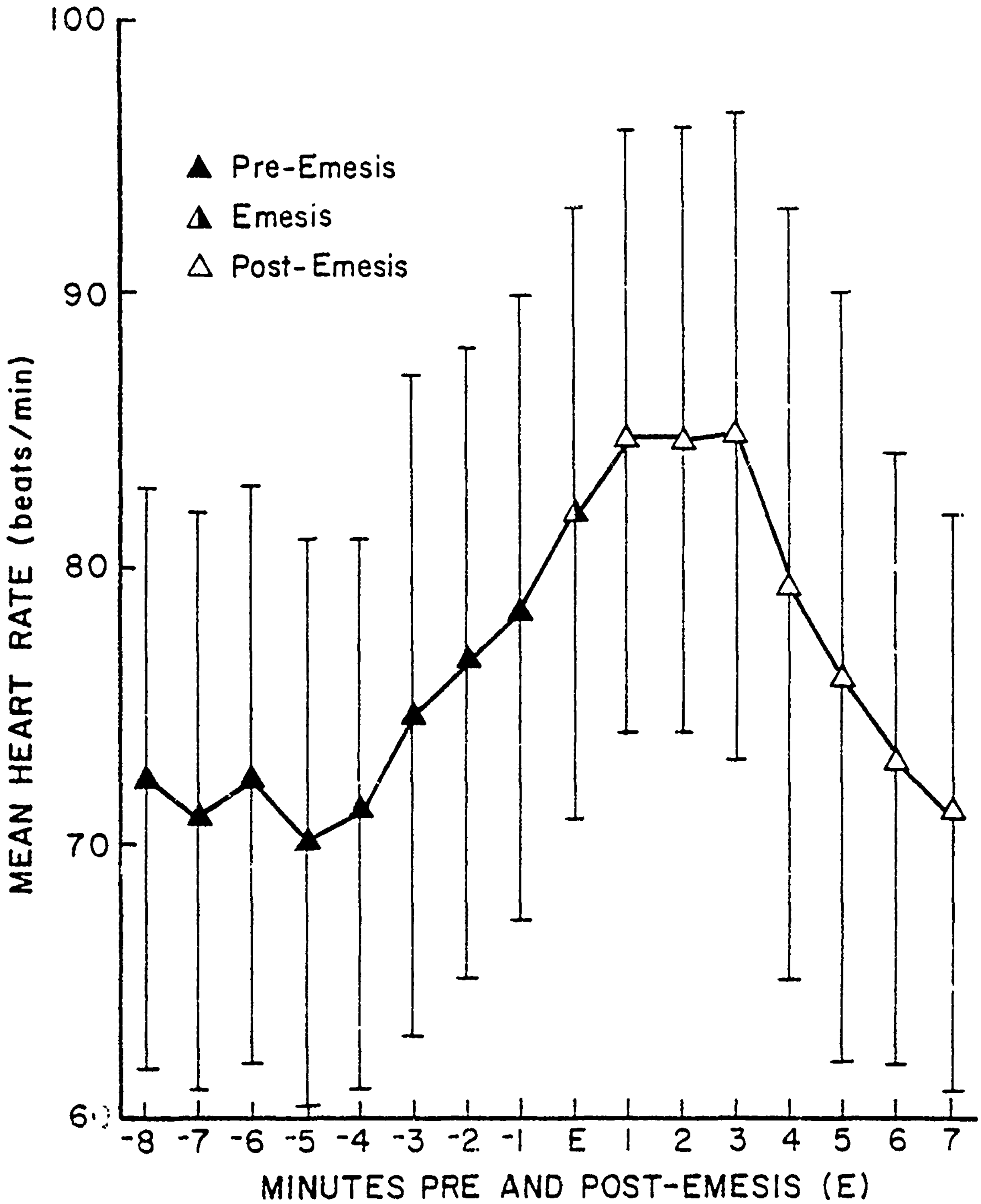


Figure 61--Average minute heart rate before, during and following the emesis episode

compartment translational motion measures are provided in Table 18. As the number of correlations provided in Table 18 is large, only a cursory statement will be made regarding the observed associations at this point. More indepth considerations are provided with the factor analysis and multiple regression results.

Examination of Table 18 indicates several general relationships between the physiological data and the measures of test compartment translational motion characteristics. First, the magnitude of daily mean frequency changes between steaming days show consistently lower correlations with physiological changes than do acceleration characteristics. It must be remembered that vessel frequencies were equivalent across steaming days while small but significant differences were found in compartment acceleration levels between days at sea. Acceleration measures show greater associations with observed physiological changes than do longitudinal measures. Finally, rms acceleration measures provided slightly higher correlations with physiological changes than did maximum spectral amplitude measures.

Correlations were also computed between physiological measures and angular plus heave ship motions recorded at the WPB's center of gravity located within five feet of the test compartment. Results provided in Table 19 indicate that roll and vertical accelerations were generally associated with

TABLE 18--Correlation matrix of physiological and WPB testing compartment translational motion measures.

Vessel Motion Characteristics	MSSS	Urine Output	Urine Sp. Grav.	Catecholamines	17-OHCS	Heart Rate	Sweat Rate
Vertical Average Frequency	-.41	.23	-.35	-.29	-.18	-.02	-.07
Lateral Average Frequency	.25	-.26	.35	-.14	.53*	-.01	.50*
Longitudinal Average Frequency	-.11	.53*	-.39	-.44	.23	.02	-.15
Vertical rms Acceleration	.70**	-.82**	.75**	.26	.53*	.35	.06
Lateral rms Acceleration	.82**	-.61**	.71**	.26	.61**	.29	.08
Longitudinal rms Acceleration	.54**	-.44*	.44*	-.13	.14	.73**	.36
Vertical Maximum Amp. Frequency	-.13	.52*	-.17	.20	-.11	-.17	.12
Lateral Maximum Amp. Frequency	.11	-.12	.00	-.27	.42	.11	-.22
Longitudinal Max. Amp. Frequency	-.45*	.66**	-.59**	-.57*	-.12	-.05	.01
Vertical Max. Spectral Amp.	.68**	-.72**	.65**	.31	.57**	.14	-.09
Laterial Max. Spectral Amp.	.73**	-.57**	.63**	.13	.63**	.14	.11
Longitudinal Max. Spectral Amp.	.48*	-.41	.35	-.07	-.03	.76**	.39

$^*p < .05$ $\quad$ $^{**}p < .01$

TABLE 19--Correlation matrix of physiological, angular and heave measures of WPB vessel motions.

Vessel Motion Measures \ Physiological Measures	MSSS	Urine Output	Urine Sp. Grav.	Catechol-amines	17-OHCS	Heart Rate	Sweat Rate
Roll Frequency	-.21	.22	-.30	.11	-.42	.10	.17
Pitch Frequency	-.17	.40	-.35	-.43	.32	.16	.21
Heave Frequency	-.28	.16	-.24	-.20	-.12	.09	.15
Roll Angle	.67**	-.50*	.58**	.21	.50*	.03	-.26
Pitch Angle	.16	-.13	.15	-.04	.07	.07	-.01
Heave rms Acceleration	.52*	-.61**	.56*	.19	.39	.27	-.01
Roll Freq. at Max. Spectral Amp.	.16	-.17	.03	-.39	.41	.25	-.14
Pitch Freq. at Max. Spectral Amp.	-.18	.26	-.24	-.23	-.05	-.11	-.35
Heave Freq. at Max. Spectral Amp.	-.13	.51*	-.18	.21	-.19	-.25	-.10
Roll Maximum Spectral Amplitude	.54*	-.42	.47*	.10	.47*	.18	-.11
Pitch Maximum Spectral Amplitude	.26	-.21	.23	-.05	-.01	-.01	-.18
Heave Maximum Spectral Amplitude	.56*	-.60**	.53*	.25	.46*	.22	-.01

*$p < .05$
**$p < .01$

physiological changes while pitch acceleration and frequency measures were not (only one significant correlation was obtained out of forty-two correlations with frequency). On the average, use of rms acceleration measures did not offer higher correlations than did maximum spectral amplitude indices.

As performance of psychomotor and cognitive tasks and physiological state changes may have interacted, correlations were computed between the indices using dockside and steaming day individual daily means.

Correlations provided in Table 20 indicate that increases in motion sickness severity were generally associated with observed decrements in task performance. Correlations obtained with physiological correlates to motion sickness showed weaker correlations with performance task decrements in the anticipated direction. Elevations in either stress hormone appear to have no relationship with subject task performance was not associated with hea . or sweat rate changes.

Correlations computed between physiological and affective state dimension scores are provided in Table 21. Inspection of the correlations obtained shows those mood dimensions which were not significantly correlated to motion sickness severity (i.e., aggression, egotism and skepticism) for the most part failed to correlate significantly with any physiological

TABLE 20--Matrix of correlations between physiological and performance measures aboard WPB.

Performance Task	MSSS	Urine Output	Urine Spec. Grav.	Catechol-amines	17-OHCS	Heart Rate	Sweat Rate
Code Substitution (# Attempted)	-.66**	.58**	-.53*	-.39*	-.42*	-.02	-.15
Complex Counting (% Correct)	-.56**	.63*	-.53**	-.20	-.23	.21	-.05
Critical Tracking (λ_c) Task	-.67**	.78**	-.72**	-.12	-.35*	.10	-.01
Nav Plot (Attempts)	-.57**	.54**	-.40*	-.19	-.22	-.25	-.07
Nav Plot (# Correct)	-.55**	.52*	-.40*	-.25	-.19	-.21	-.12
Spoke Test (Control Time)	.74**	-.51**	.51**	.32	.43**	.31	.03
Spoke Test (Experimental Time)	.50**	-.47**	.48**	.18	.20	+.16	.06
Spoke Test (Difference Time)	-.20	-.03	.00	-.43**	-.30	-.13	.09
Time Estimation	.25	.04	-.02	-.05	.25	-.32	-.24

* $p < .05$

** $p < .01$

(n = 34)

TABLE 21--Matrix of correlations between physiological and affective state measures taken aboard WPB.

Mood Dimension	MSSS	Urine Output	Urine Spec. Grav.	Catechol-amines	17-OHCS	Heart Rate	Sweat Rate
Aggression	.01	.46	-.44**	-.01	-.09	-.15	-.19
Anxiety	.87**	-.54**	.49**	.26	.56**	.09	.18
Concentration	-.59**	.69**	-.55**	-.11	-.29	.42*	-.02
Egotism	-.05	-.08	-.12	-.15	-.08	-.03	.15
Elation	-.57**	.21	-.11	-.16	-.26	-.22	-.11
Fatigue	.81**	-.25	.26	.40*	.71**	-.07	.09
Sadness	.85**	-.67**	.56**	.26	.64**	-.11	.14
Skepticism	.24	-.11	-.02	.13	.16	.21	.31
Social Affection	-.49**	.18	-.19	-.41*	-.19	-.51**	-.02
Surgency	-.75**	.47**	-.30	-.25	-.43**	-.00	-.21
Vigor	-.76**	.57**	-.58**	-.22	-.54**	.31	-.05

* $p < .05$
** $p < .01$

(n = 34)

measure. Reported elevations in anxiety, fatigue, sadness and reductions in concentration, elation, social affection, surgency and vigor were all associated with elevations in motion sickness severity. Physiological correlates of motion sickness severity (e.g., output, urine specific gravity and urinary excretion of 17-OHCS) were for the most part significantly correlated to the aforementioned mood shifts, however, magnitudes of the correlations were generally smaller than those seen with MSSS scores.

Heart rate changes were mildy correlated to subject reports of concentration and social affection. No significant correlations were obtained between mean heart rate or other mood dimensions while sweat rates were not significantly correlated to any mood dimension.

Correlations between changes in mood from dockside to steaming conditions aboard the WPB are presented in Table 22. With the exception of the dimension of aggression, which showed no significant relationship to any other mood examined, there was a pattern in mood swing from dockside to steaming conditions aboard the WPB. Increased report of negative mood (e.g. anxiety, egotism, fatigue, sadness and sketpticism) at sea was correlated with decreased report of positive mood (e.g. concentration, elation, social affection, surgency and vigor).

Table 22--Matrix of correlations between mood dimensions aboard WPB.

(n = 34)

	1	2	3	4	5	6	7	8	9	10	11
1. Aggression	1										
2. Anxiety	.11	1									
3. Concentration	.06	-.42**	1								
4. Egotism	-.06	-.11	-.06	1							
5. Elation	-.24	-.62**	.28	.04	1						
6. Fatigue	.10	.63**	-.35*	.09	-.53**	1					
7. Sadness	-.25	.66**	-.54**	.26	-.50**	.74**	1				
8. Skepticism	-.09	.25	.06	.69**	-.31	.48**	.47**	1			
9. Social Affection	-.23	-.53**	.05	.11	.57**	-.53**	-.41*	-.32	1		
10. Surgency	-.06	-.71**	.53**	-.24	.81**	-.67**	-.82**	-.48**	.52**	1	
11. Vigor	.06	-.61**	.71**	.31	.46**	-.46**	.63**	.21	.18	.62**	1

* p < .05
** p < .01

Correlations between daily individual means of mood reports obtained aboard the WPB and test compartment accelerometer summary statistics are provided in Table 23. Few significant correlations were found between mood dimensions and cabin acceleration frequency changes. The majority of significant correlations between moods and accelerometer records were evenly distributed between vertical, lateral and longitudinal rms and maximum spectral amplitude acceleration characteristics.

Correlations computed between individual daily mean performance task scores both dockside and at sea aboard the WPB are provided in Table 24.

In general task performance declines at sea were highly intercorrelated. Spoke Test (difference) times and time estimation performance, however, were only mildly correlated with a few performance measures.

While declines in code substitution, navigation plotting and Spoke Test (control) performance were not associate with elevated Spoke Test (difference) times, tasks which required more concentration and processing of sensory input were (e.g. complex counting, Spoke Test (experimental) and critical tracking). Time estimations of twelve-second intervals, unrelated to most performance task scores, were mildly correlated with Spoke Test (experimental) times.

Table 23--Matrix of correlations between mood dimensions and vessel motion measures aboard WPB at sea.

Vessel Motion Measures \ Mood Dimensions	Aggression	Anxiety	Concentration	Egotism	Elation	Fatigue	Sadness	Skepticism	Social Affection	Surgency	Vigor
Ave. Vert. Hz	.15	.00	.02	-.51*	.10	-.25	-.35	-.50*	.14	.27	.16
Ave. Lat. Hz	-.43	.41	-.12	.46*	-.02	.35	.52*	.49*	-.04	-.61**	.01
Ave. Long. Hz	.52*	-.06	.15	-.19	-.01	-.10	-.21	-.40	.02	.21	.01
Vert. rms g	-.69**	.37	.03	.53*	-.11	.44	.80**	.74**	-.50*	-.77**	.12
Lat. rms g	-.42	.45	.04	.47*	-.26	.46*	.78**	.62**	-.55*	-.73**	.05
Long. rms g	-.25	.78**	.11	.15	-.56*	.05	.38	.31	-.43	-.64**	-.50*
Vert. Max. Amp. Hz	.36	-.06	.32	-.15	-.00	-.05	-.14	-.20	-.11	.20	-.29
Lat. Max. Amp. Hz	.03	.13	.25	.28	.08	-.08	.15	.16	-.07	-.25	.20
Long. Max. Amp. Hz	.24	-.41	.40	-.13	.25	-.16	-.22	-.35	.25	.53*	.17
Vert. Max. Spectral Amp.	-.56*	.21	-.09	.54*	.02	.49*	.74*	.68**	-.41	-.66**	.29
Lat. Max. Spectral Amp.	-.36	.38	-.05	.63**	-.24	.42	.71**	.68**	-.32	-.69**	.08
Long Max. Spectral Amp.	-.30	.77**	.06	.15	-.47*	.02	.32	.34	-.36	-.60**	-.52*

* $p < .05$
** $p < .01$

(n = 34)

Table 24--Matrix of correlations between performance test scores aboard the WPB.

Performance Measure	1	2	3	4	5	6	7	8	9
1. Code Substitution (# Attempts)	1								
2. Complex Counting (% Correct)	.73**	1							
3. Critical Tracking Task (λ_c)	.63**	.85**	1			(n = 34)			
4. Navigation Plotting (# Attempted)	.77**	.81**	.77**	1					
5. Navigation Plotting (# Correct)	.69**	.81**	.77**	.94**	1				
6. Spoke Control (time)	-.76**	-.62**	-.68**	-.84**	-.80**	1			
7. Spoke Experimental (time)	-.66**	-.75**	-.78**	-.78**	-.79**	.83**	1		
8. Spoke Difference (time)	-.09	-.42*	-.41*	-.27	-.27	.01	.46**	1	
9. Time Estimation (time)	.13	.14	-.01	.13	.19	-.07	-.34*	-.12	1

* $p < .05$
** $p < .01$

Given the lack of significant changes in test compartment acceleration frequencies across the three days at sea and at dockside aboard the WPB, few significant correlations were found between such measures and task performance. On the other hand, small but significant increases in cabin acceleration levels across steaming days were correlated with a number of performance task decrements at sea. As can be seen in Table 25 the majority of correlations found were distributed primarily between the highly correlated accelerations of vertical and lateral direction.

Correlations between dockside and steaming period performance and subject reports of mood show, in general, a direct relationship between performance decline and the onset of negative mood states. Observed mood shifts were, however, essentially unrelated to changes in Spoke Test (difference) times and time estimation performance. See Table 26.

Table 25--Matrix of correlations between performance and vessel motion measures taken aboard WPB at sea.

Performance Measures / Vessel Motion Measures	Code Substitution (# Attempted)	Complex Counting (% Correct)	Critical Tracking Task (λ_c)	Navigation Plotting (# Attempted)	Navigation Plotting (# correct)	Spoke Control (time)	Spoke Experimental (time)	Spoke Difference (time)	Time Estimation (time)
Ave. Vert. Hz	.15	.44	.46	.36	.37	-.34	-.33	-.03	.26
Ave. Lat. Hz	-.53*	-.55*	-.47*	-.36	-.32	.08	.35	.49*	-.49*
Ave. Long. Hz	.14	.12	.14	.04	.05	-.03	-.03	.12	.26
Vert. rms g	-.64**	-.65**	-.64**	-.82**	-.68**	.56*	.54*	-.10	-.84**
Lat. rms g	-.65**	-.77**	-.82**	-.82**	-.77**	.73**	.81**	.14	-.79**
Long. rms g	-.13	-.39	-.64**	-.62**	-.68**	.45	.60**	.31	-.61**
Vert. Max. Amp. Hz	.02	.10	.04	.27	.12	.04	.11	.03	.12
Lat. Max. Amp. Hz	-.12	-.20	-.20	-.37	-.24	.02	.03	.06	-.16
Long. Max. Amp. Hz	.26	.52*	.51*	.57*	.56*	-.25	-.31	.02	.30
Vert. Max. Spectral Amp.	-.63**	-.69**	-.50**	-.80**	-.64**	.54*	.47*	-.15	-.68**
Lat. Max. Spectral Amp.	-.57*	-.81**	-.82**	-.76**	-.70**	.57*	.70**	.31	-.65**
Long. Max. Spectral Amp.	.03	-.34	-.61**	-.59**	-.69**	.39	.47*	.19	-.54*

*$p < .05$ (n = 17)
**$p < .01$

Table 26--Matrix of correlations between mood dimension and performance measures aboard the WPB.

Performance Measures / Mood Dimension	Code Substitution (# Attempted)	Complex Counting (% Correct)	Critical Tracking Task (λ_c)	Navigation Plotting (# Attempted)	Navigation Plotting (% correct)	Spoke Control (time)	Spoke Experimental (time)	Spoke Difference (time)	Time Estimation (time)
Aggression	.04	.03	.14	-.03	-.03	.03	-.01	.13	.47**
Anxiety	-.57**	-.43**	-.65**	-.54**	-.54**	.65**	.47**	-.04	.31
Concentration	.41*	.71**	.71**	.45**	.42*	-.43**	-.44**	-.20	-.25
Egotism	-.33*	-.54**	-.32*	-.56**	-.49**	.15	.30	.48**	-.30
Elation	.50**	.27	.32*	.51**	.46**	-.56**	-.32	.05	-.25
Fatigue	-.69**	-.45**	-.36**	-.49**	-.43**	.65**	.35*	-.28	.17
[illegible]	-.75**	-.69**	-.69**	-.65**	-.64**	.69**	.56**	-.10	-.14
Skepticism	-.56**	-.44**	-.27	-.60**	-.53**	.39*	.34*	.21	-.32
Social Affection	.63**	.29	.25	.56**	.49**	-.75**	-.55**	.22	.15
Surgency	.69**	.63**	.57**	.69**	.66**	-.64**	-.48**	.01	-.03
Vigor	.29	.35*	.48**	.18	.20	-.33	-.18	.24	-.30

*$p < .05$ (n = 34)
**$p < .01$

To aid in the interpretation of the obtained correlations in Tables 17-26, a principal components factor analysis was performed using twelve measures of WPB testing compartment motions, seven physiological indices, eleven mood dimensions nine performance task scores and measures for thermal conditions scores. Forty-one variables were reduced to ten factors which accounted for 98.3 percent of the total variance. The ten factors were then rotated orthogonally to obtain a quartimax solution. The quartimax rotated solution is summarized in Table 27.

Examination of the factor structure socre matrix in Table 27 reveals several relationships, or patterns, between the dependent and independent variables. The first factor obtained accounted for the largest portion of the total variance and appears to be concerned with motion sickness. Aside from the high positive loading of MSSS scores, the factor was correlated with reductions in urine output and elevations in urine specific gravities and excretion rates of 17-OHCS. No significant relationships were found between the motion sickness factor and heart, sweat or catecholamine excretion rates.

The motion sickness factor also possessed high correlations with the majority of the performance task decrements and mood shifts observed aboard the WPB at sea.

TABLE 27--Quartimax-rotated factor structure matrix.

WPB Measures \ Factors	1	2	3	4	5	6	7	8	9	10
MSSS	.93	----	----	----	----	----	----	----	----	----
Urine Output	-.75	----	----	----	----	----	----	----	----	----
Urine Sp. Gravity	.69	----	----	----	----	----	----	----	----	----
Catecholamines	----	----	----	----	----	----	----	----	----	-.79
17-OHCS	.61	----	----	----	----	----	----	---	----	----
Heart Rate	----	----	.31	----	----	----	----	----	----	----
Sweat Rate	----	----	----	----	----	----	----	----	.82	----
Critical Tracking	-.86	----	----	----	----	----	----	----	----	----
Nav-Plot Attempts	-.34	----	----	----	----	----	----	----	----	----
Nav-Plot Correct	-.81	----	----	----	----	----	----	----	----	----
Time Est.	----	----	----	-.72	----	----	----	----	----	----
Spoke Control	.85	----	----	----	----	----	----	----	----	----
Spoke Experimental	.73	----	----	----	----	----	----	----	----	----
Spoke Difference	----	----	----	----	-.8S	----	----	----	----	----
Code Substitution	-.83	----	----	----	----	----	----	----	----	----
Complex Counting	-.81	----	----	----	----	----	----	----	----	----
Aggression	----	----	----	-.30	----	----	----	----	----	----
Anxiety	.79	----	----	----	----	----	----	----	----	----
Concentration	-.59	----	----	----	----	----	----	----	----	----
Egotism	----	.79	----	----	----	----	----	----	----	----
Elation	-.59	----	----	.57	----	----	----	----	----	----
Fatigue	.72	----	----	----	----	47	----	----	----	----
Sadness	.92	----	----	----	----	----	----	----	----	----
Skepticism	.45	.78	----	----	----	----	----	----	----	----
Social Affection	-.56	----	-.70	----	----	----	----	----	----	----
Surgency	-.87	----	----	----	----	----	----	----	----	----
Vigor	-.58	.54	----	----	----	----	----	----	----	----
Temp.	-.60	----	.58	----	----	----	----	----	----	----
Humidity	.68	----	-.67	----	----	----	----	----	----	----
Vert. Hz	----	-.66	----	----	----	----	----	-.56	----	----
Lat. Hz	----	----	----	----	----	----	----	----	.68	----
Long. Hz	----	----	----	----	----	----	.80	----	----	----
Vert. rms	.73	.49	----	.59	----	----	----	----	----	----
Lat. rms	.79	----	----	----	----	----	----	----	----	----
Long. rms	.53	----	----	----	----	-.69	----	----	----	----
Vert. Max Hz	----	----	----	----	----	----	----	.96	----	----
Lat. Max Hz	----	----	----	----	----	----	.90	----	----	----
Long. Max Hz	----	----	----	----	----	----	----	----	----	.67
Vert. Max Amp.	.69	----	----	----	----	----	----	----	----	----
Lat. Max Amp.	.74	----	----	----	----	----	----	----	----	----
Long. Max Amp.	----	----	----	----	----	----	----	----	----	----
% of Variance Accounted for by Factor	36.9	15.0	9.1	8.4	6.9	6.7	4.6	4.5	3.5	2.7

NOTE: All factor structure scores less than .45 were arbitrary omitted for the sake of clarity.

Independent variable loadings on the first factor indicate changes in mean daily acceleration levels from dockside to steaming days were more closely related to motion sickness than frequency characteristics. Caution must be exercised with this finding for accelerometer records made aboard the WPB showed no significant differences in frequency response across steaming days while acceleration levels changed slightly.

The high loadings of test compartment temperatures and relative humidity on the first factor were most likely fortuitous. The test compartment was cooler and more humid at sea than during the dockside testing periods.

The second factor obtained accounted for fifteen percent of the total variance and is somewhat more difficult to interpret than the first factor. The factor structure scores obtained indicate that subject self-concern, skepticism and vigor increased as test compartment vertical frequencies decreased and acceleration levels increased. Although it is possible that changes in the dynamics of the testing compartment were responsible for the aforementioned shifts in mood, it is more likely that such relationships were artifacts of an experimental design which was sensitive to baseline shifts in the data.

Examination of individual mood adjective check list responses shows a progressive reduction in subject reports of

egotism, skepticism and vigor as the experiment progressed. Subjects were exposed to the WPB at sea over three consecutive days; hence, progressive subject habituation may have led to such reductions. Nonsignificant declines in test compartment vertical frequencies were found from the first to the third day at sea while vertical accelerations concomitantly increased. It is likely that relationships between such mood shifts and vertical motion characteristics were due to coincidence.

The third factor's structure scores indicate that elevations in subject heart rates and reductions in feelings of social affection were associated with elevations in testing compartment temperatures and lowered humidities.

The fourth factor obtained accounted for 8.4% of the total variance. Declines in time estimate intervals, or increased error, were associated with reductions in aggression scores, elevations in reports of elation and vertical rms acceleration increases. Given the data structure employed in the analysis, the relationship of the aforementioned dependent variables to an acceleration characteristic indicates the changes observed occurred across steaming days; hence, increased error in time estimation, decreased feelings of aggression and increased elation occurred as the steaming days progressed and vertical rms accelerations increased slightly.

The fifth factor, which accounted for 6.9% of the variance, shows declines in Spoke Test (difference) completion times were essentially unrelated to other dependent and independent variables.

The sixth factor obtained shows increased reports of fatigue were not only associated with motion sickness but were inversely related to test compartment longitudinal rms acceleration levels. As noted before, test compartment acceleration levels increased slightly as the steaming days progressed. As such, declines in daily reports of fatigue with the daily progression of the experiment may have led to a coincidental relationship. The sixth factor accounted for only 6.7% of the variance examined.

The seventh and eighth factors were unrelated to dependent variables changes and as such are not discussed.

The last two factors obtained account for the least amount of the observed variance and are the most difficult to interpret as only two variables showed any significant loadings in each factor. The factor structure scores obtained for the ninth and tenth factors, however, indicate that sweat rate changes were unrelated to urinary catecholamine excretion rates and that changes in either variable were not associated with changes in any other dependent variable examined.

Table 28: Correlation matrix of vessel motion measures aboard WPB.

	Motion Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	Roll Hz	1																							
2.	Pitch Hz	.98	1																						
3	Heave Hz	99	.96	1																					
4.	Vertical Hz	99	.97	99	1																				
5.	Lateral Hz	.99	.97	.99	99	1																			
6	Longitudinal Hz	.99	.97	.98	.99	.99	1																		
7.	Roll Angle	-.18	-.10	-.23	-.19	- 18	-.16	1																	
8.	Pitch Angle	75	.75	.72	.73	.75	.73	.16	1																
9	Heave rms g	-.15	- 03	-.19	- 15	-.15	-.12	.70	-.10	1															
10.	Vertical rms g	-.03	.10	-.09	-.03	- 03	.01	71	.08	.83	1														
11	Lateral rms g	.02	.10	-.04	.01	.02	.04	.89	.14	.80	.82	1													
12.	Longitudinal rms g	.06	.22	.02	.05	.06	.10	.46	.23	.64	.63	.58	1												
13	Roll Hz at Spectral Max. Amp.	.07	.04	.08	.06	.07	02	.05	.04	.08	-.04	.04	-.12	1											
14.	Pitch Hz at Spectral Max. Amp.	.17	-.01	.19	.16	16	.13	-.40	.10	-.58	- 65	-.40	-.60	.22	1										
15.	Heave Hz at Spectral Max. Amp	-.10	- 21	-.09	-.12	- 10	-.15	-.41	-.19	-.44	-.53	-.45	- 54	.10	41	1									
16.	Vert. Hz at Spectral Max. Amp.	-.01	- 11	-.01	-.03	-.01	-.06	-.44	-.03	-.45	-.57	-.44	- 34	.21	50	00	1								
17	Lat. Hz at Spectral Max. Amp.	.25	.22	.27	.23	24	.22	-.33	.18	-.16	-.01	-.10	-.17	.32	.14	.18	.11	1							
18	Long. Hz at Spectral Max. Amp.	-.14	-.32	-.11	-.12	-.13	-.14	-.32	-.10	-.50	-.52	-.40	-.57	.13	.59	.13	.40	.01	1						
19	Roll Spectral Max. Amp.	- 01	.08	-.06	-.02	-.01	.02	.87	.08	.77	.74	.95	.55	.06	-.40	-.42	- 42	-.03	-.48	1					
20	Pitch Spectral Max Amp.	04	- 11	.04	.03	.04	-.02	- 07	.23	-.26	- 28	-.09	- 27	.34	.58	.40	.47	.01	.67	-.21	1				
21.	Heave Spectral Max. Amp	-.07	.06	-.12	-.07	-.07	-.02	.74	.08	.89	.89	.78	.66	04	-.60	- 46	-.44	-.04	-.49	74	-.26	1			
22	Vert. Spectral Max. Amp.	-.06	.05	-.11	-.06	-.05	-.02	.71	.04	.79	.94	.78	.49	-.01	-.53	-.41	-.47	.05	-.46	.72	-.25	.90	1		
23	Lat. Spectral Max. Amp.	-.03	.06	-.09	-.04	- 03	-.02	.62	.06	.66	.74	.72	.59	-.15	-.34	-.43	-.39	-.10	-.47	.73	-.20	.65	.71	1	
24	Long. Spectral Max. Amp.	.00	.14	-.04	-.02	-.01	-.01	.31	.19	.53	.46	.40	87	.02	-.47	-.34	-.16	-.15	-.42	.39	-.11	.57	.37	.42	1

Using a two-tailed significance test:

correlations > 33 (p < .05)
correlations ≥ .43 (p < .01)

Multiple Regression Analysis Results

Examination of intercorrelations between thirty minute samples of vessel and test compartment motion data revealed several very high correlations. See Table 28. To insure a reasonable degree of orthogonality between the vessel motion predictors in the following regression analyses two courses of action were taken.

First, vessel center of gravity and test compartment motion measures were separated into two populations. Second, each population of motion measures was examined for large intercorrelations ($r > .60$). Those highly correlated variables were grouped into subsets and a single measure was then selected to represent the particular subset in the following regression analysis.

Selection of a particular vessel motion variable to represent a particular subset was based upon previous research findings, the orthogonality of the candidate representative variable with other candidate representative measures and the degree of perturbations, if any, in the collection of the particular measures. In short, selection preference was given to vertical measures in the majority of cases, despite generally higher correlations seen with lateral indices. See Tables 29 and 30.

TABLE 29--Representative translational test compartment motion measures employed in multiple regressional analyses.

Representative Predictor	Predictors Represented
Vertical Hz	Lateral Hz Longitudinal Hz
Vertical Hz at Spectral Max. Amp.	----
Lateral Hz at Spectral Max. Amp.	----
Longitudinal Hz at Spectral Max. Amp.	----
Longitudinal rms g	Vertical rms g Laterial rms g
Vertical Spectral Max. Amp.	Lateral Spectral Max. Amp.
Longitudinal Spectral Max. Amp.	----

TABLE 30--Representative roll, pitch, and heave motion measures at the vessel's center of gravity employed in multiple regression analyses.

Representative Predictor	Predictors Represented
Heave Hz	Roll Hz Pitch Hz
Roll Hz at Spectral Max. Amp.	----
Pitch Hz at Spectral Max. Amp.	----
Heave Hz at Spectral Max. Amp.	----
Roll rms g	----
Pitch rms g	----
Heave rms g	----
Roll Spectral Max. Amp	----
Pitch Spectral Max. Amp.	----
Heave Spectral Max. Amp.	----

Once two populations of acceptable vessel motion predictors were obtained, MSSS scores were regressed against each population of motion predictors and other independent measures such as steaming day, time of day, and test compartment temperature (humidity was dropped as a predictor because of its high correlation to temerature) in a stepwise hierarchical manner. The entrance hierarchy was dependent upon the dependent variable under consideration, previous research findings and results obtained from the factor analysis. Hierarchies used are discussed with each multiple regression analysis.

Translational and angular with heave motions were examined separately in multiple regression analysis of motion sickness severity. Combining the two populations of motion measures severely reduced the number of predictors due to multicolinearity problems. Furthermore, the coordinate systems differed; all angular and heave measures were based upon a geocentric coordinate system while test compartment translational coordinates were rigid with the geometry of the test compartment.

Individual half-hour MSSS scores collected aboard the WPB at sea were regressed against the following independent variables in a stepwise manner using the following hierarchy:

a) vertical rms acceleration
b) vertical average frequency
c) vertical maximum spectral amplitude
d) vertical maximum spectral amplitude frequency
e) laterial maximum spectral amplitude frequency
f) longitudinal maximum spectral amplitude
g) longitudinal maximum spectral amplitude frequency
h) time of day
i) test compartment temperature
j) steaming day

Preference in the entrance hierarchy was given to vertical motion measures based upon the findings of McCauley et al. (1976), despite slightly higher observed correlations with lateral measures. Acceleration measures were entered before their associated frequencies based upon the higher factor loadings obtained with acceleration measures in the factor analysis. Time of day, or exposure length, was entered into the regression analysis before test compartment temperature as independent studies had found temerature to be inconsequential in motion sickness onset or severity (Johnson and Wendt, 1964b· McClure et al., 1971). Finally, test compartment temperature was entered before steaming day as it was believed that very low MSSS scores might be susceptible to thermal sweating influences which would outweigh differences in susceptibility between subject populations or habituation across steaming days.

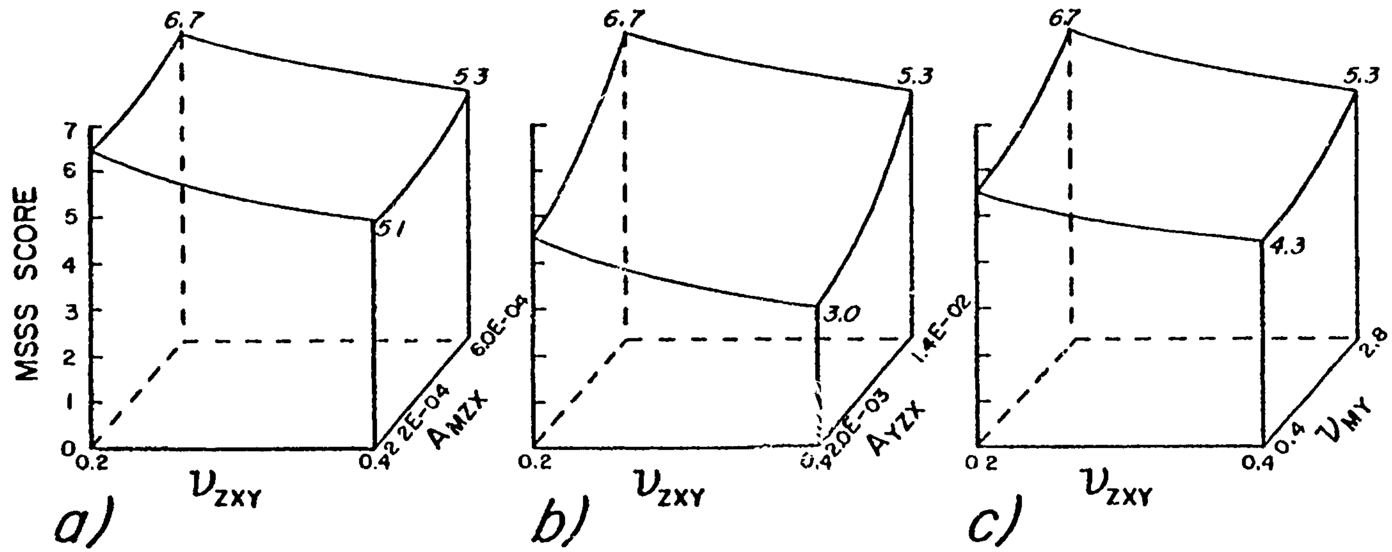
After initially screening all variables for significance in predicting MSSS scores, those variables found to be significant contributors were reentered into a stepwise

regression analysis along with their second and third-order polynomials and first-order cross products.

Those predictor terms found to account for significant portions of the variance were then examined for consistency by randomly selected subsets of the data. Additionally, the presence of autocolinearity within the data was rejected using a Durbin-Watson test. The final regression model is presented in Figure 62.

The regression coefficient beta weights obtained indicate test compartment average freuency characteristics were far more important than compartment acceleration levels in accounting for the observed fluctuations in motion sickness severity. Additionally, the MSSS response to test compartment average frequency characteristics shows motion sickness severity increases in a nonlinear manner as frequency declines. Elevations in test compartment maximum vertical or lateral amplitude, vertical, lateral or longitudinal rms accelerations, and longitudinal maximum sp 'tral amplitude frequencies led to linear increases in motion sickness severity.

A sample of three-dimensional response surfaces generated from the regression equation in Figure 62 show motion sickness severity is most severe when average test compartment frequencies were low and acceleration levels high.



$$MSSS = -8.68\nu_{ZXY} + 2.77\nu_{ZXY}^2 + 334.13A_{MZX} + 185.68A_{YZX} + 0.69\nu_{MY} + 4.24$$

(S.E.)	(3.12)	(1.06)	(84.30)	(55.40)	(0.24)	
(BETA WT.)	(-3.06)	(2.89)	(0.51)	(0.47)	(0.39)	

$r = 0.72$
S.E. = 0.73
$n = 810$

WHERE:

ν_{ZXY} = average vertical (lateral or longitudinal) frequency (Hz)

ν_{MY} = longitudinal frequency at maximum spectral amplitude (Hz)

A_{YZX} = longitudinal (vertical or lateral) RMS acceleration (g)

A_{MZX} = maximum vertical (lateral) spectral amplitude (g)

Figure 62--Motion sickness symptomatology severity (MSSS) scores regressed against test compartment translational frequency, and acceleration levels

Motion sickness severity was least when frequencies were high and acceleration levels low.

Given the second-order response of MSSS to average test compartment frequency(s), the second derivative with respect to average test compartment frequency was computed to determine the frequency at which a maximum or minimum MSSS score would be expected. The second derivative obtained indicated that the function possessed a minimum of 1.57 Hz which was well beyond the range of the data and, thus, unconfirmable. The function did not possess a maximum point.

Of the predictors investigated, vertical and lateral maximum spectral amplitude frequencies, longitudinal maximum spectral amplitudes, time of day, test compartment temperature or relative humidity and steaming day variables were not found to play significant roles in the observed fluctuations in MSSS scores.

To compare the relative contributions of roll, pitch and heave vessel center of gravity motion characteristics upon motion sickness severity, individual half-hour MSSS scores were regressed against the following independent variables using the hierarchy specified below:

a) heave rms acceleration
b) average frequency
c) heave maximum spectral amplitude
d) heave maximum spectral amplitude frequency
e) roll angle
f) roll maximum spectral amplitude
g) roll maximum spectral amplitude frequency

h) pitch angle
i) pitch maximum spectral amplitude
j) pitch maximum spectral amplitude frequency
k) time of day
l) test compartment temperature
m) steaming day

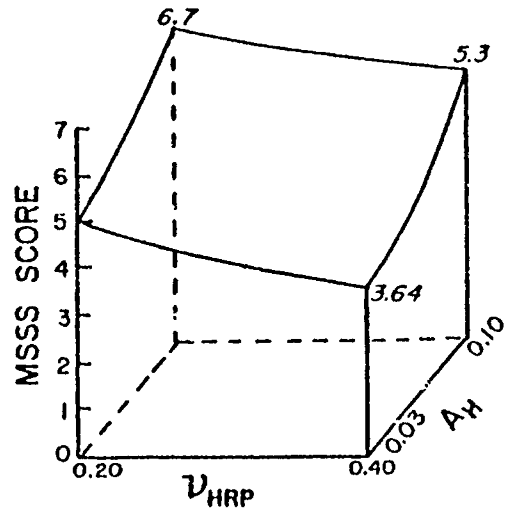
The logic behind the above entrance hierarchy is equivalent to that employed with the translational regression analysis with the exception that correlational results provided in Table 19 were considered instead of actor analysis loadings.

Results obtained, following the analytical distillation process described with the translational motion analysis, are summarized in Figure 63. Of the thirteen first-order predictors initially examined, only two predictors, average heave (roll or pitch) frequency and heave rms acceleration were found to account for significant portions of MSSS variance at sea. Average vessel center of gravity frequency characteristics were found to account for more of the observed variance in MSSS than acceleration measures; a finding which concurs with the translational motion analysis results. Similarly, vessel center of gravity average frequencies were related to MSSS scores in a nonlinear manner while heave acceleration changes exhibited a linear relationship. The first-order cross product failed to account for a significant portion of the observed variance.

The response surface in Figure 63 reaffirms graphically the provocativeness of lower frequency, higher acceleration conditions despite the difference in coordinate systems used between translational and angular with heave accelerometer measures and the opportunity for errors in equating vessel center of gravity recordings to those actually experienced within the test compartment itself. Given the size of the WPB and the fact that the center of gravity was within five feet of the test compartment it is estimated that errors in equating the motions would be within a five percent margin.

Although angular measures other than roll and pitch were not considered in the anlaysis, it appear that the angular motions studied, and possibly average angular motion frequencies, played little, if any, part in motion sickness genesis or severity.

For the following regression analysis MSSS scores were treated as independent variables. Treatment of MSSS scores as independent data was deemed justified; given the anticipated manipulation of motion sickness severity by octatonal course changes and the findings of previous studies which indicate motion sickness itself, and not the motion environment per se was responsible for changes in ADH and other hormone secretion rates.



$$MSSS = -8.02\nu_{HRP} + 2.01\nu_{HRP}^2 + 23.91A_H + 5.81$$

(2.19)	(0.58)	(5.86)	(S.E.)
(-3.72)	(3.55)	(0.47)	(BETA WT.)

$r = 0.68$
S.E. $= 0.77$
$n = 810$

WHERE:

ν_{HRP} = average heave (roll or pitch) frequency

A_H = heave rms acceleration (g)

Figure 63--Motion sickness symptomatology severity (MSSS) scores regressed against vessel center of gravity angular and heave frequency and acceleration levels

Individual two-hour total void urine volumes were regressed against the following predictors in a stepwise hierarchical regression analysis:

a) MSSS score
b) time of day
c) test compartment temperature
d) translational vessel motion characteristics not found to contribute to motion sickness genesis or severity

Given the results of previous laboratory research which found relationships between motion sickness severity and ADH blood levels, MSSS scores were initially entered into the regression equation. Time of day, or urine sample sequence, was entered into the regression equation next as dockside plots of urine sample volumes showed consistent increases as the testing period and associated hydration procedure progressed.

As elevations in test compartment temperature might have increased subject sweat rates and insensible water loss, thus reducing urine output volumes, their entry into stepwise regression analysis followed the time of day variable and preceded test compartment translational motion characteristics not asociated with motion sickness genesis. The inclusion of test compartment motions not associated with motion sickness was designed to address the possibility of dynamically induced changes in urine output (i.e., changes in glomerular filtration rates associated with circulatory changes).

Examination of polynomials and first-order cross products of those predictors initially found to account for significant changes in urine output volumes led to the regression result summarized in Figure 64. Of the predictors examined, only MSSS scores and time of day measures were found to account for significant portions of the variance in urine output data recorded both dockside and at sea aboard the WPB. Temperature or relative humidity changes within the test compartment, steaming day and test compartment motions not related to motion sickness were not associated with observed changes in urine output.

The regression equation obtained and a plot of two-hour means of urine output volumes against average MSSS scores shows motion sickness severity level to be the largest contributor to urine output changes. Plotting a mid-day sample regression line shows the nonlinear relationship found between motion sickness severity and urine output. On the average, urine output reached a maximum when MSSS scores approached 1.18. As motion sickness severity increased, or decreased, urine output was reduced at an increasing rate. The decrease in urine output associated with MSSS scores lower than 1.18 reflects early morning dockside MSSS reports where symptomatology associated with the stress of continuous performance testing was negligible. Early morning urine

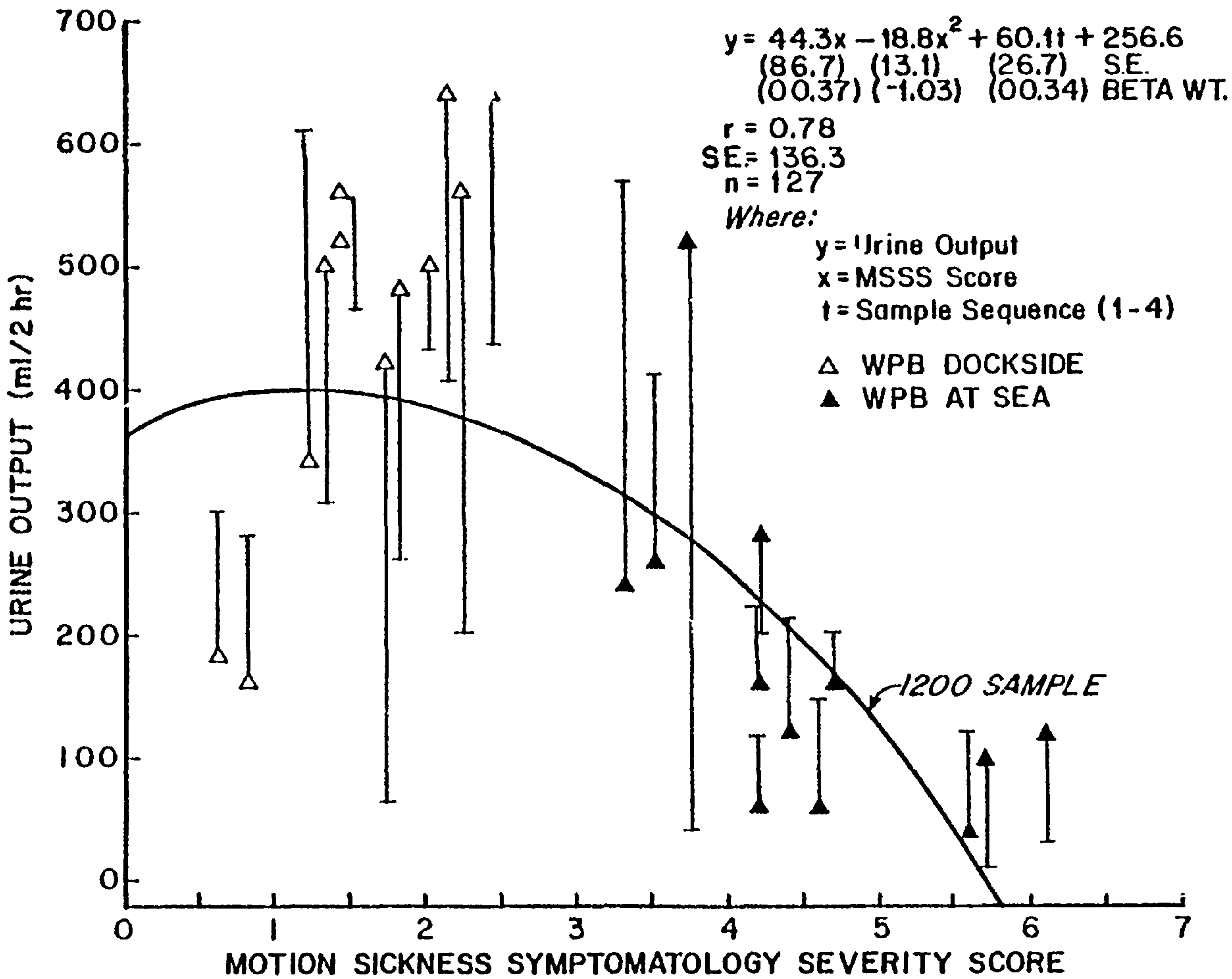


Figure 64--Urine output as a function of motion sickness symptomatology severity

sample volumes were always smaller than samples later in the day because the cumulative fluid intake was relatively small.

The regression equation in Figure 64 indicates urine output volumes increased on the average by approximately 60 ml every two hours as the hydration procedure progressed. In spite of the adjustment made for time of day change, large individual differences led to a rather large standard error of the estimate.

Individual two-hour urine sample specific gravities aboard the WPB were regressed against MSSS scores, time of day, test compartment temperature and test compartment motion characteristics not associated with motion sickness, using the same hierarchical stepwise procedure employed with urine outut data. The results, which are summarized in Figure 65, show only motion sickness severity and time of day, or urine sample collection sequence, to be of significance in accounting for changes observed in the specific gravity of urine. Examination of the regression coefficient beta weights shows MSSS scores to account for a significantly greater portion of the total variance than did time of day. Elevations in motion sickness severity led to increased urine specific gravities while samples collected later in the day were more dilute.

A mid-day sample least-squares fit of the data shows that urine specific gravity increased at a nonlinear rate as

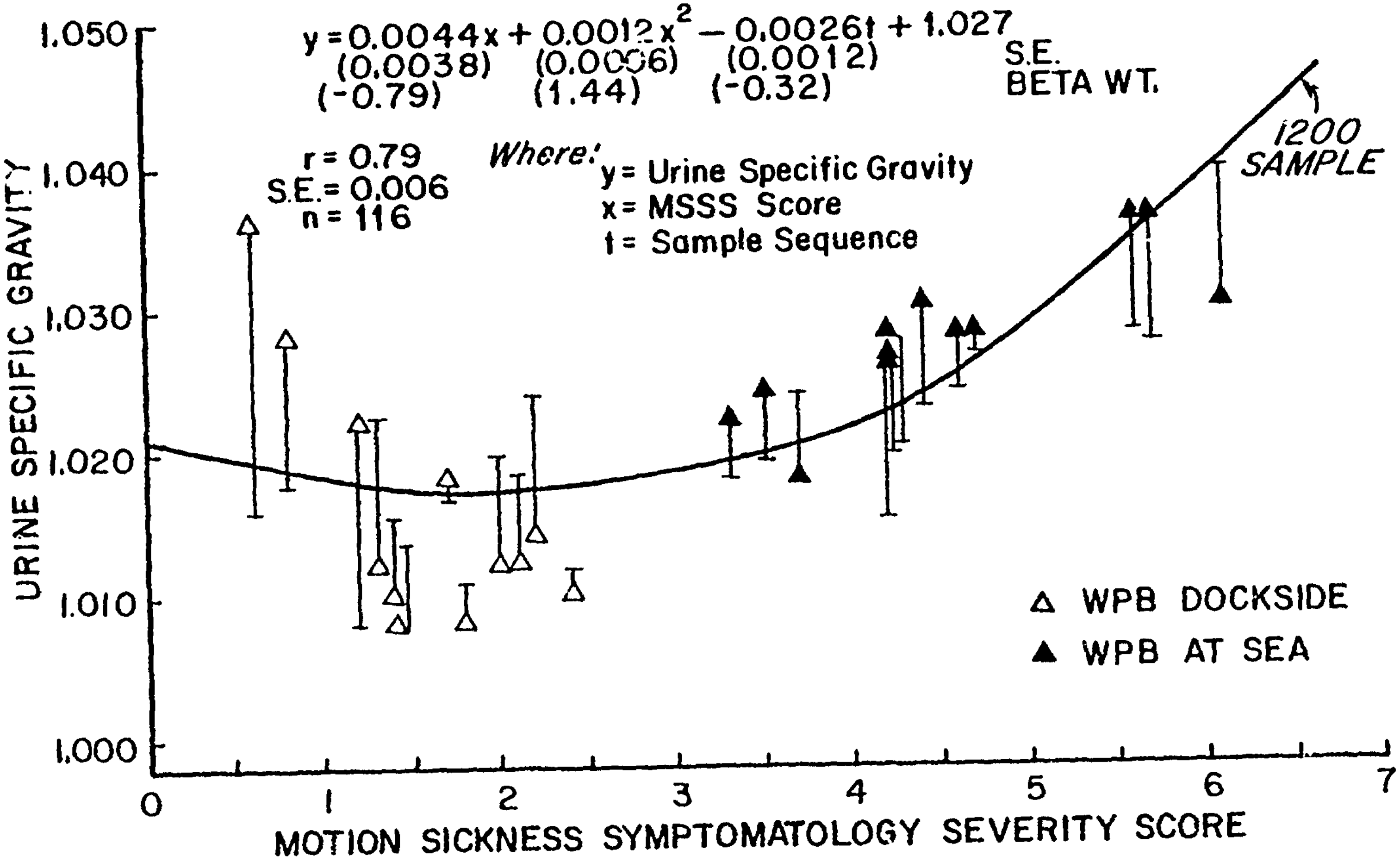


Figure 65--Urine specific gravity as a function of motion sickness symptomatology severity

MSSS scores increased from a value of 1.83. Changes in urine specific gravity values did not occur at a marked rate, however, until MSSS scores were greater than or equal to 4.0.

Given the opportunity for subject induced error in providing total void urine samples, it was anticipated that urine specific gravity data would possess a closer relationship with MSSS scores than that of urine output data. Comparing the multiple correlation coefficients obtained with urine output and specific gravity regression equations fails to support such a hypothesis. Yet the relative magnitude of the standard error of the estimate for urine specific gravity was smaller than that obtained with urine output data.

Levels of 17-OHCS contained in individual two-hour urine samples collected aboard the WPB were regressed against MSSS scores, time of day, test compartment temperature, and test compartment translational motion characteristics using the hierarchical stepwise regression procedure described for urine output and specific gravity.

Results indicated that only the first-order term for MSSS scores accounted for a significant portion of the observed variance in 17-OHCS excretion rates. In spite of considerable individual variability in excretion rates both dockside and at sea, changes in MSSS scores accounted for 58% of the observed variance in 17-OHCS excretion. The linear

relationship found between urinary excretion rates of 17-OHCS and motion sickness severity is presented in Figure 66.

Similar analysis of individual urine catecholamine levels found the first-order MSSS term to be the only predictor to account for a significant portion of the observed variance. Although the results, summarized in Figure 67, show catecholamine excretion rates were not significantly associated with independent measures other than motion sickness severity, MSSS scores accrued only slightly more than twelve percent of the variance observed.

Similar regression analysis approaches taken with individual 25 minute average heart rates and sweat rates sampled every 30 minutes showed no significant relationships with MSSS scores, time of day, test compartment temperature or test compartment motions not related to motion sickness genesis.

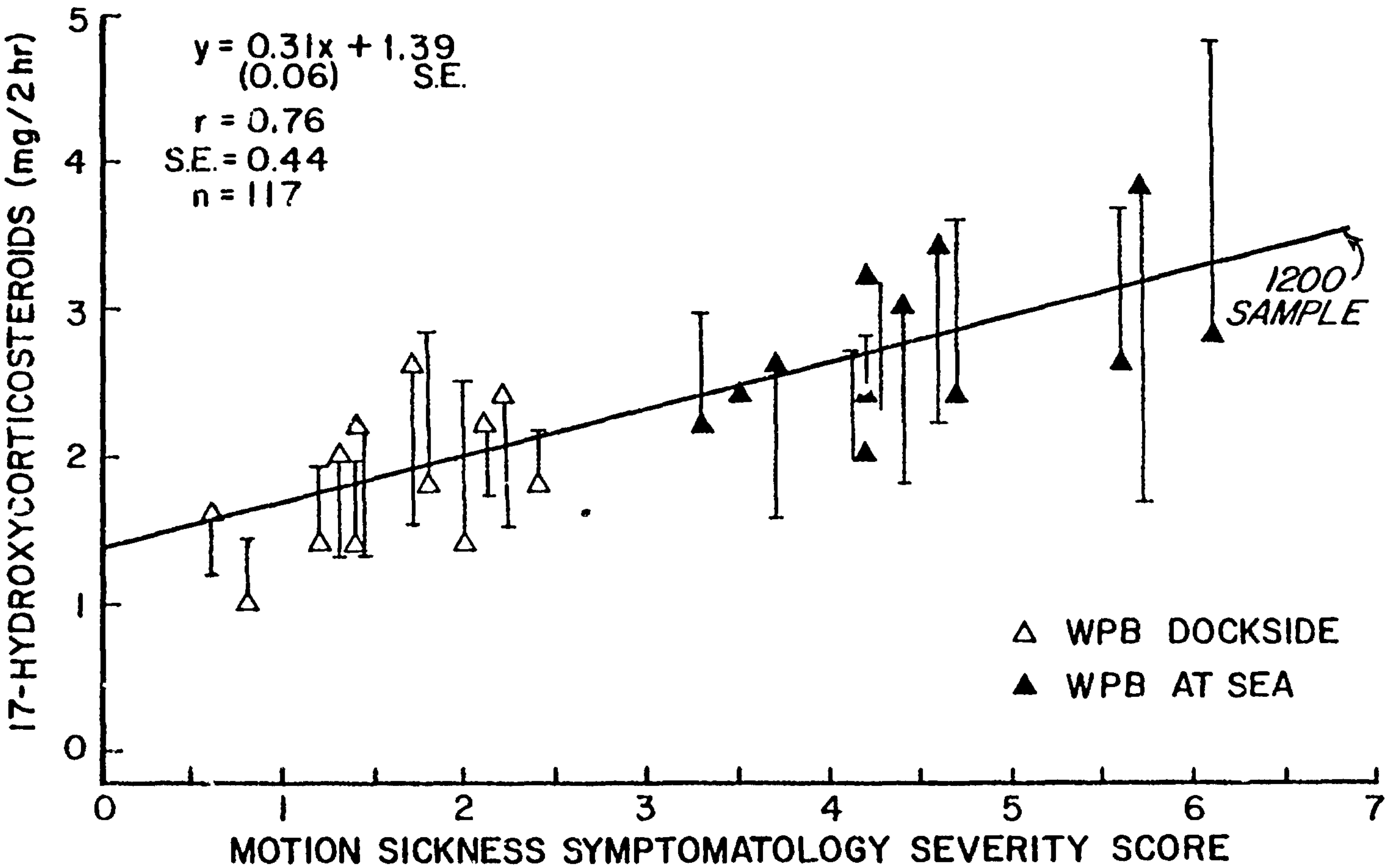


Figure 66--Urinary excretion rate of 17-hydroxycorticosteroids as a function of motion sickness symptomatology

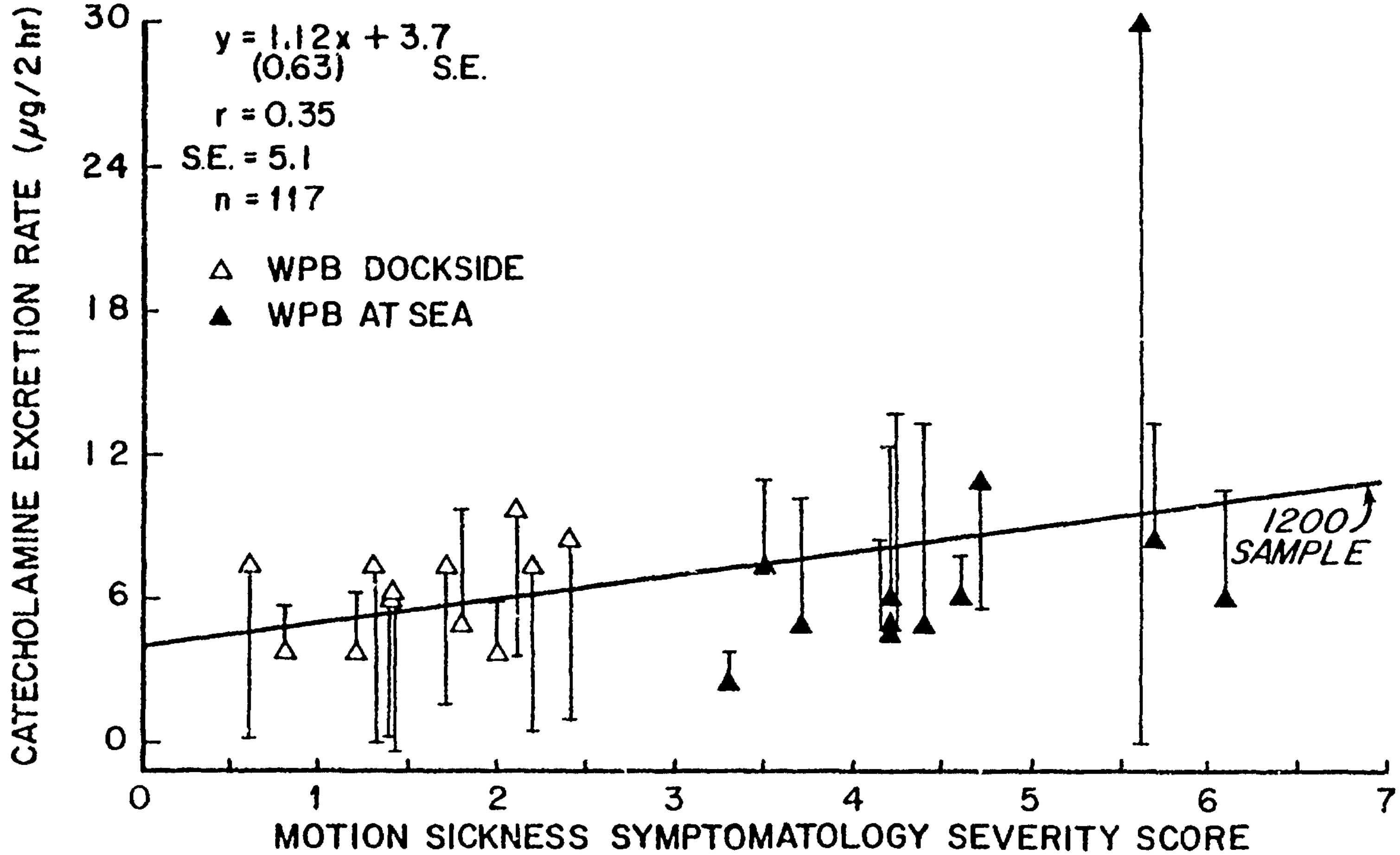


Figure 67--Urinary excretion rate of catecholamines as a function of motion sickness symptomatology

To examine the relative consequences of independent variable changes aboard the WPB at sea upon subject affective state, mood scores obtained from individual MACL data sheets were regressed against the following variables in the hierarchy specified:

a) MSSS Score

b) Lateral maximum spectral amplitude frequency

c) Vertical maximum spectral amplitude

d) Longitudinal maximum spectral amplitude

e) Vertical maximum spectral amplitude frequency

f) Time of day

g) Testing compartment temperature

Because motion sickness rather than the test compartment accelerations was believed to be the primary cause for mood shifts, those acceleration characteristics which were found to account for significant changes in motion sickness severity were dropped from the regression analysis to allow successful inversion of the correlation matrix. Those test compartment acceleration characteristics which were unrelated to motion sickness were entered into analysis for consideration of biodynamic influences upon mood. Finally, time of day influences and thermal environment changes were entered into the regression equation. Results from the analyses are summarized in Table 31.

Table 31--Beta weights of regression coefficients from regression of mood scores against independent variables.

Mood Dimension Score / Predictors	MSSS Score	Lat. Max. Amp. Hz	Vert. Max. Amplitude[1]	Long. Max. Amplitude	Vert. Max. Amp. Hz	Time of Day	Temp.	R^2 of β*
Aggression	4.01 **	0.05	0.17	0.15	0.17	-0.21	-0.12	0.19
Anxiety	3.03 **	-0.10	0.12	0.39	-0.06	-0.66*	-0.63 *	0.47
Concentration	0.54	0.13	0.06	0.06	0.12	-0.42*	-0.50 *	0.18
Egotism	-3.91 **	0.09	0.01	0.03	0.07	0.17	0.16	0.27
Elation	-1.78 *	0.10	0.04	0.01	0.20	0.34*	0.34 *	0.23
Fatigue	0.88	-0.07	0.16	0.02	0.11	0.61*	0.43 *	0.24
Sadness	3.08 **	0.03	0.17	0.10	0.05	0.03	-0.06	0.51
Skepticism	3.60 **	0.07	0.02	0.07	0.01	-0.11	-0.08	0.32
Social Affection	1.10 *	0.04	0.14	-0.07	0.01	0.08	0.20	0.44
Surgency	-3.80 **	0.14	0.13	-0.09	-0.12	0.29*	0.50 *	0.54
Vigor	-2.50 **	0.43	0.05	0.08	0.60	-0.03	0.18	0.31

* $p < .05$
** $p < .01$

[1] Represents lateral maximum spectral amplitude as well.

The magnitude, direction and statistical significance of the predictor variable beta weights indicated, with the exceptions of subject fatigue and concentration, that mood shifts at sea were due to the onset and increasing severity of motion sickness or the vessel motions responsible for motion sickness onset. Those test compartment acceleration characteristics represented by the measures in Table 31 which were unrelated to motion sickness severity played no significant role in the mood shifts observed at sea.

Subject reports of concentration or fatigue were not significantly mediated at sea by either motion sickness or test compartment acceleration measures unrelated to motion sickness. However, test compartment temperature increases and progression of the testing period accounted for significant declines in concentration and increases in fatigue.

Aside from the impact of motion sickness upon subject mood, time of day and thermal changes mediated moods such as anxiety, elation and surgency.

Regression of mood scores against MSSS scores showed that reports of aggression, fatigue, egotism, sadness, skepticism, surgency and vigor were greatest during periods when nausea was severe. The aforementioned mood dimension scores decreased if motion sickness severity decreased or increased to the point of emesis. Anxiety scores did not exhibit a maxima or minima point within the motion sickness

score range, while mood dimensions such as concentration and social affection exhibited minimum levels for MSSS scores near dockside levels. See Figure 68.

An identical analytical approach to that described above was taken for individual psychomotor performance task scores generated at sea aboard the WPB. Results, summarized in Table 32, showed changes in code substitution, complex counting, critical tracking, navigation plotting and Spoke Test (control) performance were significantly related to changes in motion sickness severity. There was a significant decline in the number of code substitutions completed as the testing period progressed. Otherwise, no predictors, except MSSS scores, were found to account for significant shifts in subject performance at sea.

Motion sickness symptomatology severity score changes accounted for large portions of the variance observed in test scores at sea. Exceptions were the Spoke Test (experimental), Spoke Test (difference) and time estimation performance changes, which were not significantly associated with changes in any predictor variable examined.

Performance task scores generated during dockside and steaming periods aboard the WPB were regressed against MSSS scores to examine the relationship between task performance and motion sicknes severity. Results of the regression analyses are graphically summarized in Figure 69.

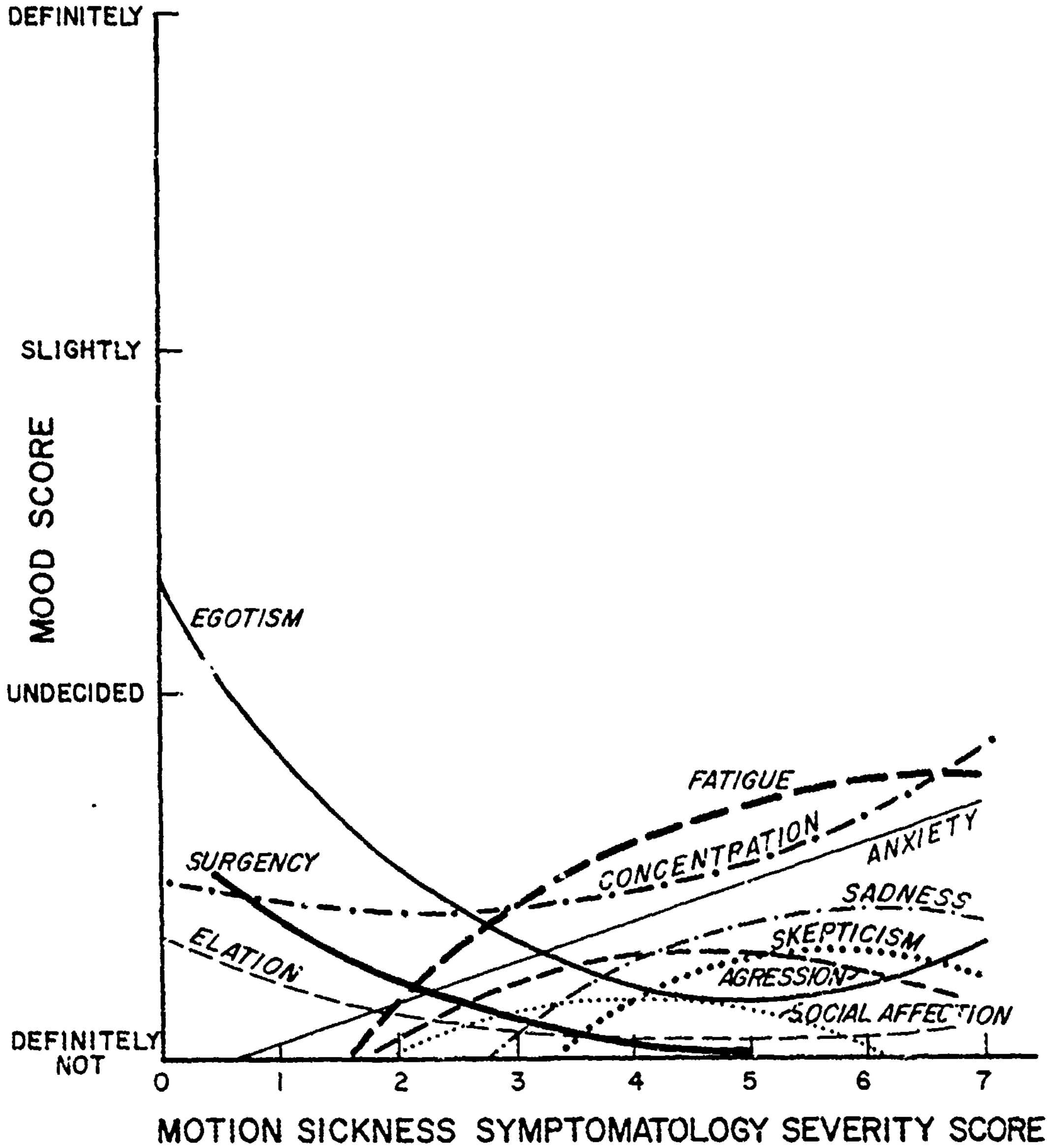


Figure 68--Mood report as function of motion sickness severity.

Table 32--Beta weights of regression coefficients from regression of performance task scores against independent variables.

Performance Task Score \ Predictors	MSSS Score	Lat. Max. Amp. Hz	Vert. Max. Amplitude[1]	Long. Max. Amplitude	Vert. Max. Amp. Hz	Time of Day	Temp.	R^2 of β*
Code Substitution (Attempts)	-2.14 *	-0.15	-0.14	0.12	-0.09	-0.31 *	0.01	0.44
Complex Counting (% Correct)	-3.72 **	0.21	0.04	0.08	-0.17	0.04	0.03	0.62
Critical Tracking (λ_c)	-1.54 *	-0.03	0.02	-0.09	0.25	0.40	0.42	0.35
Navigation Plotting (Completions)	-1.74 **	-0.07	0.10	-0.11	-0.02	0.06	0.05	0.86
Navigation Plotting (# Correct)	-1.13 **	0.06	0.07	0.07	-0.10	0.23	0.03	0.66
Spoke Test (control) times	1.62 **	0.17	0.11	0.01	0.09	0.05	0.08	0.68
Spoke Test (experimental) time	0.83	-0.03	0.09	0.03	-0.03	0.07	-0.29	.00
Spoke Test (difference) times	0.59	-0.31	-0.14	0.04	-0.20	0.19	-0.33	.00
Time Estimation (12 sec.)	-1.40	0.03	0.12	0.11	0.05	0.25	0.46	.00

* $p < .05$
** $p < .01$

[1]Represents lateral maximum spectral Amplitude as well.

TASK	SCORE Max.	Min.
Code Substitution (CS)	110.0	0.0
Complex Counting (CC)	90.0	0.0
Critical Tracking (CTT)	5.4	3.0
Nav/Plot Attempts (NAVA)	30.0	0.0
Nav/Plot #Correct (NAV C)	30.0	0.0
Spoke Test (control) (SPC)	45.0	30.0
Spoke Test (experimental) (SPE)	150.0	90.0
Spoke Test (difference) (SPD)	75.0	69.0
Time Estimation (TE)	13.5	10.5

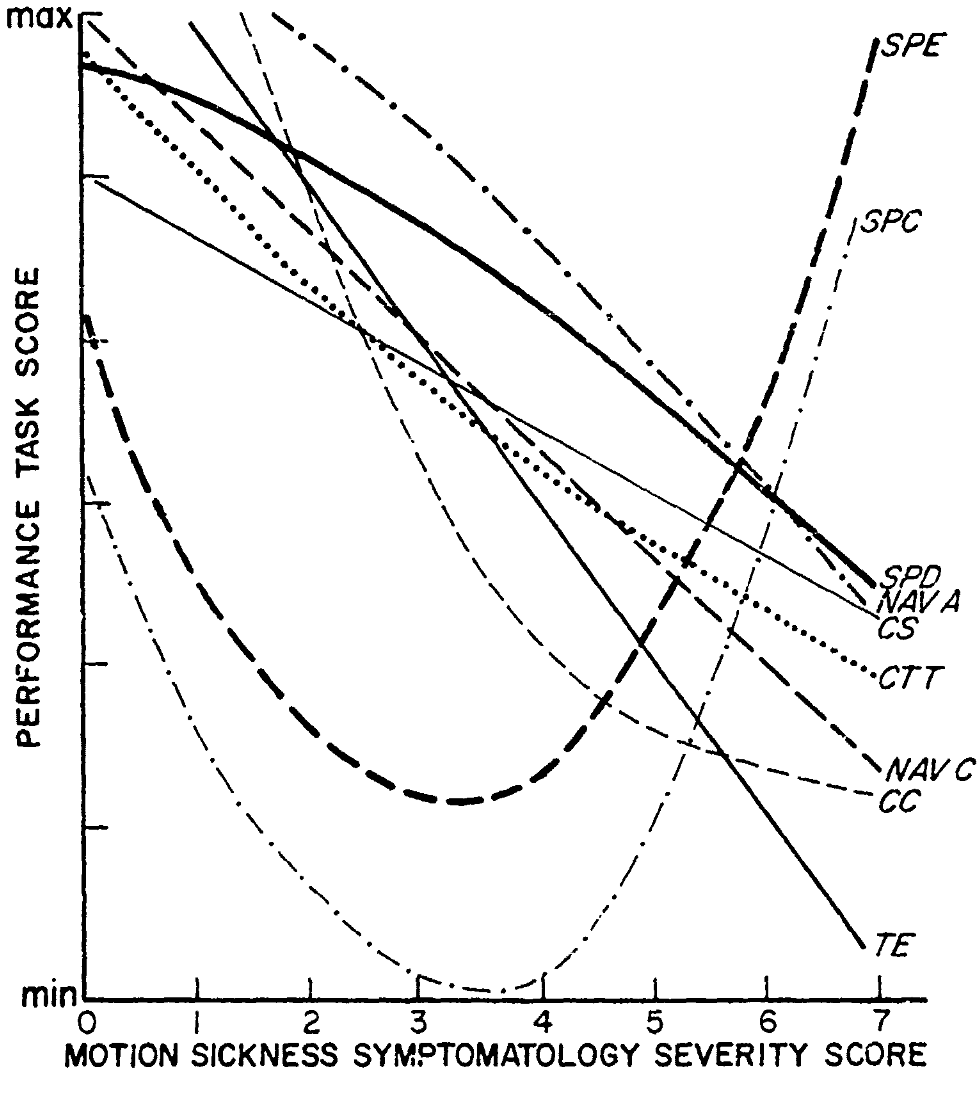


Figure 69--Psychomotor task performance as a function of motion sickness severity.

As seen in Figure 69, the statistically generated functions between task performance and MSSS score show near linear declines in performance with increasing levels of sickness. Spoke Test (control), Spoke Test (experimental) and complex counting performance show improvements as MSSS reaches emesis levels. The improvements may be a result of a temporary symptom reduction following the emesis episode.

Subject Experiment Debriefing Questionnaire Responses

Responses from subject debriefing questionnaires (See Appendix C) were collected and some are summarized in Table 33. Questionnaire responses received indicated that the majority of subjects believed vessel pitching to be the most detrimental to their well being, and rolling action to be of least consequence. Pitching action also was perceived to be the greatest detriment to their performance, and rolling actions were again believed to produce the least problems.

Table 33--Test subject assessment of vessel motion influences upon their well being and performance.

Factor*	Heave	Pitch	Roll
Well Being			
Most Detrimental	33%	50%	22%
Least Detrimental	6%	22%	72%
Performance			
Most Detrimental	28%	61%	33%
Least Detrimental	6%	33%	72%

*Note: Some subjects were unable to judge any difference between the effects of pitch and heave upon their performance or well being. In those cases their response was counted separately as both pitch and heave in the summary statistic.

DISCUSSION

From the analysis of test compartment accelerometer records it is clear that test compartment dynamics were more severe aboard the 95' WPB Coast Guard Patrol Boat at sea than either the 89' SSP Navy Semi-Submersible Platform or the much larger 378' WHEC Coast Guard High Endurance Cutter. Given the sea state 3 conditions experienced during the steaming days, test compartment motions aboard the SSP and WHEC were relatively stable. The SSP provided only a slightly more dynamic environment than the WHEC.

Measured physiological response to whole body motion stimuli experienced aboard the SSP and WHEC was minimal. No significant changes occurred in motion sickness symptomatology, urine output rate, urine specific gravity, mean heart rate or forehead sweat rates from dockside to steaming conditions. A moderate increase in the excretion of catecholamines was found aboard the SSP at sea ($\bar{X} = 58.8\ \%$ $p < .01$) and a small elevation in 17-hydroxycorticosteroids was obtained aboard the WHEC during steaming periods ($\bar{X} = 18.8\%$ $p < .01$).

The lack of motion sickness, the slight improvement in thermal conditions at sea, the relative stability of the test

compartments, and the lack of any meaningful perturbations in subject affective state or psychomotor performance make explanation of the observed hormone excretion rate changes aboard the SSP and WHEC difficult. Possibly there was a novelty or excitement associated with going to sea, particularly aboard a vessel as unique looking and riding as the SSP. Furthermore, a base line shift may have occurred in the physical or psychological burden associated with continuous and repetitive performance testing endured eight hours a day for six consecutive days. The analysis used for dockside versus at sea hypothesis testing was sensitive to gradual changes in variables as the experiment progressed because the experimental paradigm resulted in the collection of a majority of the steaming exposure data following dockside sampling.

Although no definitive explanation can be provided for the observed hormone excretion rate elevations found aboard the SSP and WHEC at sea, it is evident such elevations were not due to motion sickness or whole body accelerations.

Low frequency whole body vibrations experienced aboard the WPB at sea were associated with significant changes in many of the physiological measures. All subjects experienced severe motion sickness during their exposure to the WPB with only one subject failing to vomit during the eight hour exposure. The MSSS scores generated aboard the WPB at sea indicated that subjects generally suffered severe nausea throughout the day

with severity waxing and waning between emesis and moderate levels of nausea as the WPB steamed about the octagon.

Analysis of the relationships between changes in test compartment linear acceleration characteristics and motion sickness severity, though hampered by several cases of multicolinearity between motion spectra summary statistics, showed the most important contributing factor to motion sickness severity to be that of test compartment average frequency of acceleration. Due to multicolinearity between vertical, lateral and longitudinal frequency changes resulting from octagonal steaming pattern course changes, it was not possible to determine the relative importance between these frequencies in the provocation of motion sickness.

Within the limits of the data, motion sickness became increasingly severe as test compartment average frequencies of acceleration declined at any given acceleration level. This finding agrees with results obtained from a previous aircraft field study which, although acceleration levels were unknown, found motion sickness to be most severe aboard the aircraft producing the lowest average vertical frequency (Kennedy et al., 1972). The results were also consistent with laboratory studies using simple vertical oscillating platforms (Alexander et al., 1945a,b,c,d; Alexander et al., 1947; O'Hanlon and McCauley, 1974; McCauley et al., 1976).

Both emesis and subemesis degrees of motion sickness severity were a function of test compartment frequency and acceleration characteristics, in a manner similar to that described by the motion sickness incidence (MSI) prediction model provided by O'Hanlon and McCauley (1974). That is, low frequency high acceleration environments were more provocative than higher frequency low acceleration conditions. Unfortunately, the maximum turning point in motion sickness incidence predicted at 0.17 Hz by the MSI model could not be verified because the WPB average vertical frequency of acceleration did not range below 0.20 Hz. Moreover, the regression obtained between MSSS scores and WPB test compartment average frequency of acceleration was only a second order function which possessed a positive second derivative; hence, only a minimum MSSS response to compartment frequency well beyond the data range could be obtained.

In addition to test compartment average frequency of acceleration influences, elevations in maximum spectral amplitudes of vertical/lateral accelerations, rms (g) accelerations in longitudinal/vertical/lateral directions and longitudinal maximum spectral amplitude frequency were respectively associated with linear increases in motion sickness severity. The changes in motion sickness severity associated with the above variables were, however, far less

important than those due to compartment average frequency, as evidenced by the regression coefficient beta weights obtained.

Given the multicolinearity between compartment accelerations in the vertical, lateral and longitudinal directions, it as not possible to determine the relative importance of specific acceleration directions upon motion sickness severity, as had been hoped. It is noteworthy that of all linear acceleration characteristics or their representative predictors examined, only longitudinal maximum spectral amplitude changes failed to account for significant changes in motion sickness symptomatology severity. Moreover, it was the only linear acceleration measured used in the regression analysis which was unrelated to vertical accelerations.

The reported importance of vertical accelerations in provoking motion sickness was supported by the results obtained from regression of MSSS scores against WPB vessel center of gravity heave, and angular motion spectral characteristics. Geocentric accelerometer records made at the WPB's center of gravity, located approximately five feet from the center of the testing compartment, showed only heave/roll/pitch average frequency(s) and heave rms (g) accelerations to account for significant changes in motion sickness symptomatology. It is not possible to reject the importance of roll or pitch average frequency (due to their high correlations with heave frequency) in motion sickness genesis, however, no other angular motion

parameters were found to account for significant changes in MSSS scores.

This analysis involved subemesis motion sickness symptomatology severity, as well as emesis incidence reports from subjects whose heads were not secured while exposed to a variety of simultaneous heave, roll and pitch accelerations. Thus, the results provide stronger support for the original assertion by McCauley et al., (1976), that heave, and not roll or pitch motions are primarily responsible for motion sickness genesis aboard contemporary seagoing vessels.

When subjects were questioned about the importance of vessel heave, roll and pitch motions upon their feeling of well being the vast majority reported roll or pitching actions to be of least consequence. Less agreement was obtained when subjects chose vessel motion characteristics which were most detrimental to their well being. From subject responses and other comments provided on experiment debriefing questionnaires, it appeared subjects had difficulty in perceptually distinguishing between heave and pitch motions. Because pitching action changes were more easily acknowledged, both visually and proprioceptively, than changes in heave acceleration, it may be that subjects attributed increased motion sickness severity to increasing pitching motion as the WPB headed into the seas and heave accelerations increased. It is interesting that, despite the lack of importance found with

roll accelerations in motion sickness in the regression analyses, approximately a fifth of subject responses indicated vessel roll to be most detrimental to their well being.

Approximately half of the observed variance in motion sickness symptomatology severity scores remained unaccounted for by the independent variables measured, although the relationships found between motion sickness severity and WPB test compartment acceleration characteristics support several of those found in the laboratory under much simpler acceleration environments. Several factors may be responsible for the amount of "noise" found in the data.

First, the low end of the MSSS scale employed was subject to extraneous influences unrelated to motion sickness. As the experiment was conducted in a tropical climate and subjects were periodically assessed as they performed numerous repetitive psychomotor and cognitive tasks for an eight hour period, reports of thermal sweating, headache, yawning, physical and mental fatigue, normal bowel movements and drowsiness contributed to the magnitude of obtained scores in varying degrees throughout the day. The sensitivity of the MSSS scale to subject reports of minor symptoms which were unrelated to motion sickness is evidenced by low MSSS scores obtained aboard each vessel class during dockside periods.

Aside from some imperfections in the MSSS score as an index of motion sickness severity in this experimental

paradigm, exposure to complex whole body motion environments required the use of summary statistics of accelerometer power spectra. Aside from the inability of a few power spectrum descriptors to adequately represent the total acceleration dosage received, power spectral characteristics other than those examined, such as directional acceleration phase relationships and harmonic characteristics, may have been important in provoking motion sickness.

Finally, the results and interpretation of the present data must be tempered by the understanding that accurate test compartment accelerometer records do not provide information regarding the vestibular, visual or proprioceptor stimuli actually received by the subjects. Variations in head orientation and movements controlled by the subjects, transmissivity factors, associated visual field movements, proprioceptor stimuli and changing psychological demands placed upon subjects performing a variety of tasks as the vessel steamed about the ocatgon, may have contributed significantly to the unexplained variance in MSSS scores.

Though several possible contributing factors to motion sickness onset and severity could not be addressed in this study, it is clear that many findings concerning motion sickness incidence obtained in the laboratory under much less complex motion environments were replicable within the range of acceleration stimuli presented aboard the WPB.

Several other physiological responses found in laboratory studies of motion sickness were replicable in this study. Pronounced antidiuresis was found in subjects aboard the WPB during steaming periods. Urine output declined on the average by 60.0% ($p < .001$) while specific gravities increased by 100.0% ($p < .001$) when compared to dockside levels. The severity of subemesis motion sickness experienced appears to be a significant factor in the observed fluctuations in urine output and specific gravity data. However, episodes of emesis, profuse sweating associated with vomiting incidents, thermal sweating and insensible water loss due to changes in thermal and metabolic burdens at sea may have contributed.

Results obtained from regression of individual urine output data against MSSS scores, test compartment temperature, time of day and vessel motion characteristics unrelated to motion sickness genesis, reject the significance of small changes in thermal exposure or compartment accelerations unrelated to motion sickness in the observed antidiuresis. Sweat rates did not differ significantly between dockside and steaming periods, nor between vessels at sea. Furthermore, the observed flux in sweat rates was not correlated with either urine output or specific gravity. These results indicate the lack of any significant or sustained influence of such motion characteristics upon diuresis.

Antidiuresis was greater in subjects who experienced emesis within a given two hour sample period, than those who had not. However, reductions in urine output and concommitant elevations in specific gravities remained substantial in the one subject who had experienced only subemesis levels of motion sickness and in subjects who experienced emesis only later in the day.

The relationship between individual dockside and steaming day means of MSSS scores and urine output rates was significant ($r = -.63$, $p < .001$). The correlation improved slightly after partialling out the influence of the hydration procedure (which led significantly to increasing urine outputs as the day progressed) and all of the data collected during the dockside and steaming perods were examined ($r = -.68$).

Pronounced changes in urine output did not occur until subjects began to report moderate levels of nausea, cold sweating or drowsiness (i.e., MSSS scores greater than 4.0). This effect is seen by examination of the mid-day regression line obtained between MSSS scores and urine output data as well as the variance in the urine output data.

Similar findings were optained with the urine specific gravity data collected aboard the WPB. Individual daily means of urine specific gravity obtained dockside and at sea were significantly correlated to elevations in MSSS scores ($r = .60$, $p < .001$). Only MSSS scores and urine sample sequence were

found to be associated with significant changes in specific gravities. When the influence of the hydration procedure upon urine osmolality was partialled out, the individual two-hour samples revealed a slightly stronger correlation with motion sickness severity ($r = .68$). Again, the response of urine specific gravity to motion sickness symptomatology severity was not prominent until the MSSS scores were greater than 4.0.

The magnitude and direction or urine output and specific gravity changes and their associations with motion sickness aboard the WPB were consistent with those found during a preliminary experiment conducted aboard the WPB using a different subject population (Wiker and Pepper, 1978) and previous laboratory based studies by Taylor et al., (1957) and Eversmann et al., (1978).

The correlation between urine output volumes and specific gravities ($r = -.91$, $p < .001$) and the lack of vessel motion influences, beyond those provoking motion sickness, suggest the observed changes were in response to ADH release associated with motion sickness onset.

Given the results obtained with urine output and specific gravity data, the use of these measures as objective indices of motion sickness incidence and severity, originally suggested by Taylor and his co-workers in 1957, appears valid. Aside from the demonstrated lability of these measures in response to changing levels of motion sickness symptomatology severity,

substantial congruence was obtained between MSSS scores, urine output and urine specific gravity in correlations obtained with other physiological measures, psychomotor performance, affective state indices and the independent variables. Of the twenty-two significant correlations obtained between MSSS scores and other variables, seventeen were concurred with by urine output data and sixteen by urine specific gravity. Those measures which possessed significant but very mild correlations with MSSS scores produced congruent correlations with urine measures which failed significance tests. Although urine output and specific gravity correlations with measures significantly related to MSSS scores were generally lower in magnitude, five of the seventeen urine output and three of the sixteen specific gravity correlations exceeded MSSS correlations in magnitude.

Other physiological measures examined were less useful in signifying the onset and severity of motion sickness or the additional stress of whole body accelerations experienced aboard the WPB. Urinary excretion rates of 17-OHCS exceeded the normal daily excretion range during dockside testing periods; indicating that exposure to the testing paradigm itself was demanding. Exposure to the WPB at sea and associated motion sickness led to an average increase of 160.0% ($p < .001$) in 17-OHCS excretion from dockside levels. Changes in motion sickness symptomatology severity scores from dockside

to steaming periods aboard the WPB were highly correlated with 17-OHCS excretion rates ($r = .75$, $p < .001$).

The magnitude of the correlation must be viewed with some reservation as a 18.8% ($p < .01$) increase in excretion of 17-OHCS was found aboard the WHEC at sea and significant differences between the SSP and WHEC at sea were obtained where no significant motion sickness was reported. Furthermore, factor analysis results show the majority of negative mood shifts observed aboard the WPB at sea were largely associated with changes in both motion sickness onset and 17-OHCS elevations in the urine. The suggestion of psychological stress components inflating the correlation between MSSS scores and 17-OHCS is supported by results obtained in a previous study aboard the WPB.

Crew members from the WPB, who regularly endured motion sickness, showed little change in affective state when subjected to an earlier experimental paradigm similar to that employed in this study. The correlation obtained between their MSSS scores and 17-OHCS excretion rates was less than half that found in this experiment, even though the MSSS scores were equivalent to those found in this study, as were the magnitudes and direction of the correlations obtained between MSSS scores, urine output and specific gravities.

Finally, the degree of congruency found between MSSS and 17-OHCS correlations with other variables measured was not

promising. Of the twenty-two significant correlations obtained between MSSS scores and other variables, only ten concurring correlations were obtained with 17-OHCS data while two other significant 17-OHCS correlations disagreed in direction with the MSSS correlation.

Given that the MSSS score was the only independent variable found to account for significant changes in 17-OHCS excretion in this experiment, and that no significant catecholamine excretion rate elevations were found, the results are supportive of previous suggestions that elevations in adrenal cortical activity during aircraft aerobatics (Dahl et al., 1963; Colehour, 1965) and under laboratory acceleration conditions provoking motion sickness (Colehour and Graybiel, 1966; Eversmann et al., 1978) are responsive to vestibular input and not just psychophysiological stress alone. Though the magnitude of elevations obtained aboard the WPB concur with those seen in the laboratory and aircraft motion experiments, and the correlation to motion sickness severity is strong, the susceptibility of this index to influences unrelated to motion sickness makes the use of the measure in motion sickness assessment questionnable.

There were no significant changes found in urinary excretion rates of catecholamines from dockside to steaming conditions aboard the WPB and no differences between vessel classes at sea. Significant but mild correlations were found

between nonsignificant elevations in catecholamines and MSSS scores (r = .35), subject report of fatigue (r = .40), social affection (r = -.41), and WPB longitudinal maximum spectral amplitude frequency (r = -.57). With the exception of the vessel motion index mentioned, factor analysis results suggest that the correlations obtained were fortuitous. Inspection of the longitudinal acceleration spectral characteristics over the three days at sea provide no insight to the relationship found with catecholamine excretion rate flux aboard the WPB.

As with catecholamine excretion data no significant changes were found from dockside to steaming conditions in forehead sweat rates or twenty-five minute mean heart rates aboard the WPB. The lack of change in sweat rates from dockside to steaming exposure to the WPB was unexpected given noticeable sweating in subjects just prior to and during emesis. The variability of sweat rate data and equivalent value between dockside and steaming conditions aboard the vessels may be due to a number of factors. First, the test compartments aboard all vessels were cooler during steaming day collection periods than during the days at dockside. Second, the amount of ventilation in the test compartments was greater when steaming than during dockside periods. At the compartment temperatures and relative humidities between vessels could only be "equalized" by venting the compartments to the outside, shifting wind velocities and steaming directions did change

compartment ventilation characteristics. Ventilation was noticeably greater aboard the WPB as she headed into the seas and motion sickness severity worsened. Finally, thermal conditions in the test compartments were warm and humid. As a result the cold sweat response to motion sickness during all but the most severe periods of illness may have been shrouded by thermal sweating as demonstrated by McClure and Fregly (1972).

No significant changes in heart rate were found between dockside and steaming conditions aboard the WPB. This finding is consistent with previous investigations by Hemingway (1945) and Crampton (1955). Examining the effects of motion sickness and simple whole body acceleration exposures upon heart rate, these investigations found no significant heart rate changes, aside from brief periods of tachycardia during the act of emesis, during very low frequency whole body acceleration and associated motion sickness.

Mild tachycardia was experienced by all subjects during the act of emesis ($\overline{\Delta}$ = 19.7%, $p < .01$). Elevations in heart rates occurred in all subjects a few minutes prior to emesis and subsided a few minutes following the initiation of vomiting.

The mechanics involved in the act of vomiting may have contributed to the magnitude of the elevations seen in heart rates. However, initiation of the tachycardia episode occurred

three to four minutes prior to emesis, suggesting other processes were likely involved. The mechanisms involved with heart rate alterations prior to and during vomiting remain unclear at this point, however, given the proximity of the vasomotor center to the vomiting center in the medulla oblongata, the opportunity for influencing vagal tone of the heart exists (Borison and Wang, 1953). Also, contributions of subject anxiety and respiratory rate changes associated with the preparation for emesis cannot be ruled out as factors in heart rate shifts.

The mild seas failed to produce substantial postural challenges to the seated subjects aboard the WPB. Though subject reports of physical fatigue were significantly greater aboard the WPB than either of the other two vessels at sea, the cardiovascular burdens associated with whole body vibrations experienced aboard the WPB were apparently insufficient to raise cardiac output demands to the point requiring increased heart rate. The small variations in heart rate seen, according to factor analysis results, were associated more with changing test compartment thermal conditions and declines in subject feelings of social affection than either motion sickness or compartment dynamics endured.

The lack of meaningful change in physiological measures from dockside to steaming conditions aboard the SSP and WHEC was associated with stability in subject affective state

as well. Of the eleven mood dimensions examined aboard the two vessels, increased social affection ($p < .05$) and surgency ($p < .05$) aboard the WHEC at sea were the only changes found in mood between dockside and steaming conditions. Subjects exposed to the motion environment aboard the WPB, however, experienced shifts from dockside levels in the majority of mood dimensions examined. All MACL measures except egotism, skepticism and social affection changed with the introduction of vessel motion and associated motion sickness aboard the WPB.

Direct comparison of mood reports obtained aboard each vessel during the steaming periods showed no differences across vessels with regard to the dimension of aggression. WPB subjects reported small but significant increases in feelings of aggression, sadness and skepticism when compared to equivalent scores obtained from the SSP and WHEC. Similarly, equivalent MACL reports of concentration, egotism, elation, surgency and vigor obtained aboard the SSP and WHEC were greater than those obtained from the WPB during steaming periods. Only reports of fatigue, anxiety and concentration differed between all three vessels during the steaming periods; fatigue was lowest aboard the SSP, anxiety lowest and concentration highest aboard the WHEC.

It should be noted that although the shifts in mood from baseline levels at dockside, or between vessel classes at sea, were statistically significant, the magnitudes of the differences were generally small with mean scores ranging between score categories of "definitely not" and "undecided" or "undecided" and "slightly".

As shown in Tables 10 and 12, the largest changes in mood found aboard the WPB or between the vessels at sea occurred respectively in the dimensions of fatigue, vigor, anxiety, sadness, surgency and concentration. The WPB was the only vessel to provoke motion sickness in the subject population and the concomitant elevation in negative, and decline in positive, mood state is attributed primarily to the onset of motion sickness.

The above assertion is supported by a number of factors. First, previous investigators have consistently found fatigue, depression and anxiety to be associated with the motion sickness syndrome (Hemingway, 1944; Clark and Graybiel, 1961; Whiteside, 1965; Money, 1970). Second, as shown in Table 21, mood dimensions which exhibited the largest changes at sea possessed strong correlations with MSSS scores while at the same time exhibiting few significant and consistent correlations with test compartment acceleration characteristics (See Table 23). Third, results from factor analysis show high factor loadings of the majority of mood

dimensions upon the same factor which possessed the highest MSSS score loading. Finally, regression of mood scores obtained from the WPB during steaming days against motion sickness symptomatology severity scores, test compartment acceleration measures unrelated to motion sickness, testing compartment temperatures and time of day, showed the majority of mood changes at sea to be associated with fluctuations in motion sickness severity. Test compartment acceleration parameters unrelated to motion sickness did not account for significant changes in any mood dimension examined. Progression of the testing period and associated increases in test compartment temperatures accounted for significant portions of the variance in some mood scores (e.g. anxiety, concentration, and surgency), however, the magnitude of these relationships approaches those seen with motion sickness changes.

The lack of significance found between motion sickness severity at sea and the mood dimensions of concentration and fatigue was somewhat puzzling. It is clear, as shown in Figure 26 and 32, that the influence of the steaming environment tended to be cumulative. Hence, remission of fatigue, or enhanced concentration, with reduction in MSSS scores during various octogonal pattern possitions, would be absent and correlations would be reduced.

The results of mood score regression against MSSS scores show for the most part negative mood shifts reached a

maximum during periods of severe nausea. They decreased if motion sickness decreased or increased to the point of emesis. The improvement found in affective state with emesis levels of motion sickness may reflect the tendency for temporary symptom remission following the emesis episode. Fatigue and declines in social affection, however, continued to increase with motion sickness severity.

Though the majority of mood shifts seen at sea can best be explained by changes in motion sickness severity, it is evident that factors aside from those measured during the experiment were involved. Of those predictors found to account for significant changes in mood at sea, less than half of the total variance observed in mood scores could be accounted for by any given set of predictors. Several factors may have contributed to the unexplained variances, such as subject-subject or subject-experimenter interactions, subject bias, possible baseline shifts in the subjects' feelings toward continued participation in the experiment, possible shifts in the subjects' criteria for reportable mood changes as the experiment progressed, and measurement error associated with the MACL itself.

The differences found in MACL reports between the SSP and WHEC in mood dimensions of fatigue, anxiety and concentration at sea are difficult to explain given the lack of motion sickness and relatively stable test compartments

during steaming periods. Aside from the possible influences upon mood scores noted above, subjects may have been more anxious about the difference in ride quality between the WHEC and much smaller SSP and the possible incidence of motion sickness. At the same time, subjects may have considered the eight hour exposure to the SSP at sea a novel experience and as a result exhibited a sight alteration in mood state.

Although the direction of mood shifts found aboard the WPB at sea were predictable, the number of dimensions affected was not. Previous use of the identical MACL and scoring system in a laboratory motion generator study showed only feelings of increased fatigue and reduced vigor associated with exposures to SS 5 and concomitant motion sickness (Abrams et al., 1971). Additionally, a pilot study conducted with the WPB using a similar testing paradigm found only fatigue scores to increase significantly at sea from dockside (Wiker and Pepper, 1978).

Examination of the pilot study data shows the shifts in mood dimensions at sea from baseline levels were compable to those seen in this study; however, the sample size in this study was considerably larger than that used in the pilot study or by Abrams et al. (1971). As a result, correlations found in the pilot study between fatigue and concentration scores and MSSS scores were consistent with the present study. In addition, significant correlations were

obtained in this study with MSSS and anxiety ($r = .87$), elation ($r = -.57$), sadness ($r = .85$), social affection ($r = -.49$), surgency ($r = -.75$) and vigor ($r = -.76$) scores.

The lack of additional corroborative correlations between this and the pilot study may reflect differences in the subject populations examined. Experienced WPB crewmen were tested during the pilot study and, as a result of physiological and perhaps psychological habituation to the ride quality of the WPB, the mood reports in other dimensions were less responsive to changes in motion sickness severity.

Similar to the results of affective state response to the test compartment acceleration environments aboard the SSP and WHEC, psychomotor performance was relatively unperturbed at sea. No decrements were found in any performance task examined aboard the SSP at sea. Small but significant improvements in Spoke Test (experimental) and Spoke Test (difference) times from dockside levels were found aboard the SSP at sea. Because the majority of performance task data at sea was collected after the dockside collection periods. the improvements are attributed to practice effects.

Performance aboard the WHEC at sea remained unchanged from dockside levels in all tasks with the exceptions of slight improvements in navigation plotting performance ($p < .05$), attributable to learning effects, and decreased error in time estimation of a twelve-second interval ($p < .01$).

All tasks, with the exception of times estimation, suffered decrements aboard the WPB during steaming periods. As shown in Table 14, the largest decrements in performance aboard the WPB were found respectively in complex counting, navigation plotting, critical tracking, code substitution, Spoke Test (control), Spoke Test (experimental) and Spoke Test (difference) times.

Direct comparison of performance task scores between vessels at sea shows, with the exception of the time estimation task, subject performance levels aboard the WPB to be lower than either the SSP or WHEC. The only differences found in performance task scores between the SSP and WHEC at sea were in Spoke Test (control) times ($p < .05$) and absolute errors in time estimation ($p < .05$); both of which were greater aboard the SSP than the WHEC.

Results obtained from multivariate analyses show performance task decrements between dockside and steaming periods, with the exceptions of Spoke Test (difference) and time estimation measures, to be associated with increases in motion sickness severity scores, changes in physiological indices of motion sickness, deterioration of subject mood and variations in test compartment acceleration characteristics related to motion sickness incidence. Increases in Spoke Test (difference) times and reductions in time estimation

errors however, were not consistently associated with changes in the vast majority of independent variables examined.

Performance scores of tasks which suffered at sea aboard the WPB were found to be correlated with motion sickness severity and test compartment accelerations associated with motion sickness. Tables 20 and 25 show many of the correlations between task performance decrements and acceleration measures (particularly lateral rms g) to be greater than those seen with MSSS. Whether performance was affected directly by the accelerations endured within the test compartment, or as a result of motion sickness provoked by the accelerations, cannot be objectively determined given the degree of colinearity between MSSS scores and cabin accelerations.

Although the direct impact of the compartment's accelerations upon subject performance cannot be ignored, a number of factors support the contention that motion sickness was primarily responsible for the decrements observed.

Given the mild seas experienced, acceleration exposures aboard the WPB were mild enough to allow seated subjects to work without noticeable efforts to maintain posture or work position. Furthermore, when individual hourly test scores were regressed against MSSS scores, acceleration measures unrelated to motion sickness severity, time of day and test compartment temepratures, not one acceleration index was found to account for significant changes in performance.

Aside from the significance of time of day with code substitution scores, MSSS scores were the only variable found to account for changes in task performance. See Table 32.

Those tasks which were most susceptible to direct dynamic interference (e.g., CTT, navigation plotting and Spoke Test) did not consistently show the largest decrements at sea. For example, complex counting performance, which was not vulnerable to direct acceleration influences, experienced considerable decrement at sea.

Finally, the quantity of performance was reduced while the quality was not. The percentage of errors in the navigation plotting task remained unchanged from dockside to steaming conditions aboard the WPB while errors in the code substitution task were essentially nonexistent.

Assuming for the moment motion sickness was the prime factor in the decrements observed in performance at sea aboard the WPB, the question arises as to how motion sickness interfered with the majority of psychomotor performance tasks examined. One might be tempted to attribute declines in test scores to perturbations in perceptual, cognitive or motor capacities because the tasks which suffered at sea measured a number of components of human performance. A larger perspective of the data, however, suggests a different interpretation.

A pattern in the rank order of performance task decrement at sea shows that those tasks which required sustained periods of performance, and which offered greater opportunity for subjects to self-pace their performance, suffered the most (e.g. complex counting, navigation plotting). Tasks which required very short periods of effort and which were less complex in nature (e.g., Spoke Test, code substitution) suffered least.

Unfortunately time estimation performance results, which would have provided more direct insight regarding changes in perceptual aspects of performance, cannot be relied upon. In the process of recording push button initiation and termination of time estimate onto FM magnetic tape, it was later learned, the time interval could contain an error of 800 msec in magnitude. As a result, only the longest intervals were examined (twelve seconds) and the assumption was made that the errors would be random given the large number of observations. Upon inspection of the results it appears that the signal encoding induced errors may not have been random. The differences found within and between vessels in time estimates are very close to 800 msec in magnitude and since no other rational explanation can be presented for the outcomes in figures 59 and 60 the test data appear to have been compromised.

The proferred interrelationship between decrements in the remaining performance tasks during steaming day exposures to the WPB, motion sickness and subject motivation follows a line of thought established by other investigators. Birren (1949) argued human performance would be relatively insensitive to the effects of motion sickness if the tasks were simple and short in duration; however, he speculated that complex tasks, or tasks which required prolonged periods of sustained effort, would be vulnerable. Similarly, Graybiel et al. (1965) found performance in a variety of tasks could be maintained if subjects were highly motivated.

Although motivation is difficult to quantify, differences in the performance demands placed upon subjects in previous studies, as well as differences in the statistical stability of the tests administered, may explain the inconsistencies found in psychomotor performance findings between field and laboratory-based investigations of motion. In general, laboratory investigations which have concentrated upon simple or short term tasks have found few decrements in performance. When more complex tasks were administered decrements were found (Jex et al., 1976) if learning effects were not pronounced (Abrams et al., 1971).

Additionally, subjects in such studies were able to remove themselves from the provocative environments if they so desired. As a result they may have been more willing to

extend the magnitude or duration of their efforts during periods of motion sickness.

By contrast, field studies provide essentially no opportunity for subjects to avoid the provocative environment, regardless of the degree of subsequent participation in the experiment, this situation may promote more conservative or paced efforts. Moreover, the majority of tasks examined at sea have been more operationally specific and as such have tapped several dimensions of human performance simultaneously.

While the motivational set of subjects may be important in determining the magnitude of motion sickness effects upon performance, another important factor is the statistical stability of the performance task investigated. As mentioned earlier, significant learning effects have been reported in a number of tasks studied under repeated measures experimental designs (Abrams et al., 1971; Jex et al., 1976; Wiker and Pepper, 1978). Given the relatively small decrements found in subject performance on the more simple tasks examined in this study (decrements in code substitution and Spoke Tests were within 16% of dockside performance levels), use of less stable tests in the past may have shrouded decrements in simple or short tasks.

In closing it should be emphasized that the magnitude and breadth of the performance decrements reported in this

study are conservative. The subjects employed were, for the most part, experienced Coast Guardsmen familiar with both the rigors of motion sickness and vessel motion environments. Moreover, sea state conditions experienced in this study were very mild and probably did not contribute significantly to the magnitude of decrements found. Finally, if a subject failed to perform a given task(s), or was removed from the test compartment, his performance scores were considered to be missing data rather than zero scores. One subject withdrew from experiment participation after a two hour exposure to the WPB steaming environment, and another was removed from the test compartment at the discretion of the experimenter after a morning of very severe motion sickness and essentially no task performance. If these data had been incorporated into the analyses decrements in task performance would have been substantially greater than those reported.

CONCLUSIONS

Very low frequency whole body accelerations experienced aboard the 95' WPB Coast Guard Patrol Boat, as it steamed side-by-side with an 89' SSP Navy Semi-Submersible Platform (SWATH) vessel and a 378' WHEC Coast Guard High Endurance Cutter through sea state 3, provoked severe motion sickness, stress, deterioration in subject affective state and reduced levels of performance on a variety of psychomotor performance tasks. The SSP, although comparable to the WPB in size, yielded a quality of ride similar to that of the much larger WHEC. Consequently, no motion sickness, significant levels of stress, deterioration of mood or decrement in performance were found aboard the SSP or WHEC.

Motion sickness was most severe when vessel average frequencies of acceleration were lowest and acceleration levels highest. Either decreasing the acceleration level at a given frequency or increasing the motion frequency led to reductions in motion sickness severity; with changes in frequency proving to be more important than changes in acceleration levels. Several cases of multicolinearity between test compartment linear acceleration data precluded

determination of the relative importance of linear acceleration direction; however, comparisons of geocentric vertical accelerations and roll or pitch motions support a previous assertion that vertical linear and not roll or pitch motions account for motion sickness incidence aboard contemporary seagong vessels (McCauley et al., 1976).

The incidence of motion sickness and its severity were strongly correlated with antidiuresis and urinary excretion rates of 17-OHCS. Given the high negative correlation obtained between urine outupt reductions and urine specific gravity changes, along with the evidence provided by Eversmann et al. (1978), it is believed that the antidiuresis found during periods of motion sickness in this study was due primarily to release of antidiuretic hormone (ADH).

The congruency between MSSS and either urine output or specific gravity correlations with other variables of concern indicate ADH assays or use of indirect measures of ADH release can be useful in objective assessment of motion sickness severity or individual susceptibility.

Although use of total void urine volume or urine specific gravity offer the advantages of subject acceptibility, ease of collection and economy of analysis, they required necessarily long intervals between collection without the aid of catheterization; especially when motion sickness is sustained for periods of time. Furthermore,

urine output and specific gravity response to motion sickness severity have a tendency to lag if subjects are not sufficiently hydrated (e.g., in the morning following a night's rest and abstinence of fluid intake).

Despite some shortcomings with the use of urine production characteristics in the assessment of motion sickness severity, the use of 17-OHCS or other indices of the general adaptation syndrome as objective indices of motion sickness severity are not recommended. Excretion rates of 17-OHCS, though associated with motion sickness severity, provide considerably poorer relationships with nonphysiological correlates to motion sickness than measures of diuresis. At the same time large differences were seen in excretion rates of 17-OHCS between the SSP and WHEC at sea where no significant motion sickness was reported and biodynamic challenges were nearly equivalent. It is also possible that significant negative mood shifts seen with motion sickness incidence in this study may have inflated the magnitude of the relationship between motion sickness and adrenal cortical responses.

Despite the opportunity of affective state influences in 17-OHCS excretion aboard the WPB, the relationship between motion sickness and the corticoids appears far greater than that seen with catecholamine excretion. No significant responses were seen in urine catecholamine levels during

steaming day exposures to the WPB resulting in severe motion sickness; hence, use of catecholamine excretion as a gauge of motion sickness severity is not recommended in the future.

Sweat and heart rates, with the exception of mild tachycardia signalling the emesis episode, were equally ineffective in providing information regarding motion sickness severity or the degree of dynamic stress endured. The use of sweat rates should not be rejected as an index of motion sickness based upon the experimental findings of this study. The tropical climate and associated thermal sweating as well as compartment ventilation rate changes at sea may have confounded detection of a cold sweat response.

Analysis of subject self reports of mood show that small but significant shifts occurred in the majority of mood dimensions examined. The general deterioration in mood is attributable, for the most part, to motion sickness onset and severity. Motion sickness was severe and the shifts in mood small. Therefore, it is not likely that experienced crewmen, who can anticipate impending subsidence of the motion sickness episode, will experience large swings in mood with higher sea states.

The motion sickness episode is unquestionably unpleasant. If it is frequently experienced due to inherently poor vessel ride quality, or to frequent short term exposures to provocative sea state conditions, desire

for continued or future sea duty is likely to be diminished.

The incidence of motion sickness and the acceleration characteristics closely related to motion sickness severity were found to be strongly associated with the small to moderate decrements found in the majority of performance tasks examined. Declines in performance were greatest in tasks which were complex in nature, required periods of sustained performance and which offered the greatest opportunity for subjects to control the pace of their efforts. These facts, along with the reduction found in the quantity and not the quality of performance, suggest that performance decrements were due to reductions in subject motivation as a result of motion sickness rather than deterioration in the performance capacity of the subjects.

The relative contributions of motion sickness and dynamic interference to performance decrement cannot be objectively determined. High correlations found between the majority of acceleration indices and motion sickness severity scores. However, it is believed that direct dynamic interference with subject performance was minimal ring this study. Because the seas were mild, there were no obvious biodynamic challenges to subject performance and there were no significant relationships between acceleration indices (which were unrelated to motion sickness severity) and performance task scores. Had sea state conditions been

harsh, it is likely that additional decrements in performance would have been found due to biodynamic interference.

The results of this study suggest that shipboard tasks which are complex, require long periods of effort or sustained attention, viewed as nonessential, and are subject to the discretion of the crewman, are likely to suffer during periods of moderate to severe motion sickness.

These results and previous findings by independent investigators clearly indicate that motion sickness challenges the physiological, affective state and psychomotor integrity of men at sea. With proper consideration toward the ride quality of a vessel's design the incidence of motion sickness and its ramifications upon crew well being and performance can be avoided as shown by the experimental SWATH vessel; at least in sea state 3 seas.

To date the ride quality design criteria available are meager. Insufficient attention has been paid to sex and age differences in motion sickness susceptibility of potential crew populations, the interactions between vessel equipment display systems and vestibular stimulation characteristics, in motion sickness provocation and direct dynamic interference with various perceptual and motor tasks aboard ship.

Given the difficulties associated with attaining naval vessels for use in experimentation, the inability to systematically manipulate or control the acceleration stimuli

presented to subjects, and the tendency for many shipboard acceleration indices to be coupled, the most prudent approach toward establishing reliable ride quality design criteria for seagoing vessels and other transportation modes lies with the use of multiple degrees of freedom laboratory-based motion generators and periodic field tests for validation purposes. Though the simulators may produce less complex motion environments than those seen aboard ships, the results obtained in this study are largely corroborated with previous findings obtained in the laboratory.

Until further research can be conducted to validate additional acceleration and frequency regions, to refine and augment the motion sickness incidence prediction model reported by O'Hanlon and McCauley (1974) and McCauley et al. (1976), its interim use in providing vertical acceleration restriction guidelines for new vessel design and stabilization of contemporary vessels is recommended. At the same time, shiphandlers may, within the restrictions of vessel safety and mission requirements, reduce the incidence of motion sickness aboard their vessels by selecting steaming courses and vessel speeds which minimize vertical accelerations, and which avoid vertical frequencies between 0.15 and 0.25 Hz.

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APPENDIX A

APPENDIX A

PRESELECTION QUESTIONNAIRE

INSTRUCTIONS

The enclosed questionnaire has been provided in order to obtain some essential information concerning certain physical characteristics you may possess. This information will be used to help us select a representative group of test subjects for participation in the previously discussed study.

Crewmen selected as tentative candidates for participation in the sea trials will be notified within one week. At that time a more detailed description of performance measures will be presented. Demonstrations and practice sessions will be given during the more detailed briefing as well.

Strict confidentiality will apply to all information acquired in the questionnaire and only those associated with the USCG Ship Motion Research Team will have access to the information provided.

Date: ____________

CGD14 SEA TRIALS HUMAN FACTORS SELECTION QUESTIONNAIRE

Name: ______________________ Age: ________ Sex: ________

Rate/Rank: ______________________ Married: ______ Single: ______

Unit: ______________________ Height: ______ Wt: ________

1. Have you ever participated in an experiment before?

   YES _____ NO _____ When? ______________________

2. Number of months spent onboard your present ship: ____________

3. Total shipboard experience excluding your present ship:

   Ship type ____________ Time onboard in months ____________

   ____________ ____________

   ____________ ____________

   ____________ ____________

4. Have you ever been seasick? YES _____ NO _____. If YES, would you describe the experience. Please describe weather conditions, length of voyage, type of vessel, whether you recovered while at sea, (and if you became sick again), and any other factors you consider pertinent.

5. From your experience at sea would you say that you:

   Always get sick _____ Frequently get sick _____ Sometimes _____

   Rarely _____ Never _____

6. Have you ever been motion sick under any conditions other than at sea?

   YES _____ NO _____ If so, under what conditions?

7. If you vomited while experiencing motion sickness, did you:

   Feel better and remain so? ______________________

   Feel better temporarily, then vomit again? ______________

   Feel no better, but not vomit again? ________________

   Feel no better and continued to vomit repeatedly? __________

8. In general, how susceptible to motion sickness are you?

   Extremely _____ Very _____ Moderately _____ Minimally _____ Not at all _____

Name: ______________________________

9. In the past 8 weeks have you been nauseated <u>FOR ANY REASON</u>?

NO ____ YES ____. If YES, explain: ____________________________

10. In the past when you were nauseated for any reason, did you:

Vomit easily ____ Vomit only with difficulty ____ Retch and finally vomit with great difficulty ____ Could never vomit when nauseated ____ Never nauseated in life ____.

11. Have you ever vomited in your sleep after heavy partying on the previous night? YES ____ NO ____

12. What do you think your chances of getting sick would be in an experiment where 50% of the subjects get sick?

I almost certainly would __________
I probably would __________
I probably would not __________
I almost certainly would not __________

13. Most people experience faintness (not as a result of motion) 2 or 3 times a year. During the past year you have felt faint:

More than this __________
The same as this __________
Less than this __________
Never faint __________

14. How well do you understand your motives and reasons for doing things?

Very well __________
Better than most __________
About average __________
Less than average __________
Not well at all __________

15. Have you ever had an ear illness or injury which was accompanied by dizziness and/or nausea?

16. Were you a controller of a vehicle when you were motion sick?

17. Would you volunteer for an experiment where you knew that:

85% of the people became seasick? YES ____ NO ____
50% of the people became seasick? YES ____ NO ____
25% of the people became seasick? YES ____ NO ____
0% of the people became seasick? YES ____ NO ____

Name: ____________________

18. What was the highest level of education you have attained?

Eighth grade ________
High School ________
Two years in college ________
Four years in college ________
Graduate school ________

19. Most people experience slight dizziness (not as a result of motion) 3 to 5 times a year. The past year you have been dizzy:

More than this ________
The same as ________
Less than ________
Never dizzy ________

20. When you become motion sick what type of remedy do you use? (Medical or otherwise)

21. How concerned are you with your performance on:

	Very great	Great	Moderate	Little
School exams:	_____	_____	_____	_____
Shipboard Performance:	_____	_____	_____	_____
Sporting Activities:	_____	_____	_____	_____

22. Do you normally expect to perform better _____, same as _____, or worse than _____ the average person?

23. Do you smoke daily _____, infrequently _____, or never _____?

24. Do you drink alcohol daily _____, heavily at infrequent times _____, lightly at infrequent times _____, rarely _____, never _____.

25. Do you frequently take medications or drugs?

NO _____ YES _____ (If YES, do not specify at this time)

26. Have you been ill in the past year? NO _____ YES _____. If YES, specify: severity, time course and locality (on body).

27. I am _____ am not _____ in my usual state of fitness.

APPENDIX B

CGD14 SEA TRIALS HUMAN FACTORS
TEST SUBJECT CONSENT FORM

I, ________________________________ having attained my 18th birthday, and otherwise having full capacity to consent, do hereby volunteer to participate in an investigation entitled, "CGD14 SEA TRIALS HUMAN FACTORS ANALYSIS", under the direction of LTjg Steven F. Wiker USCGR.

The implications of my voluntary participation; the nature, duration, and purpose; the methods and means by which it is to be conducted; and the inconveniences and hazards to be expected have been thoroughly explained to me by LTjg Wiker, and are set forth in full on the reverse side of this Agreement, which I have initialed. I have been given an opportunity to ask questions concerning this investigation study, and any such questions have been answered to my full and complete satisfaction.

I understand that I may at any time during the course of this investigation study revoke my consent and withdraw from the study without prejudice, however, I may be required to undergo certain further examinations if, in the opinion of LTjg Wiker, such examinations are necessary for my health or well being.

________________________________ ____________

Signature Date

I was present during the explanation referred to above, as well as the Volunteer's opportunity for questions, and hereby witness his signature.

________________________________ ____________

Signature of Witness Date

I understand that I will be performing an array of cognitive and perceptual-psychomotor tasks while at dockside and at sea for a period of one week in mid April. ________

During this study I will be giving urine samples for analysis of stress hormones and specific gravities. ________

I understand that I will have surface electrodes attached to my chest during the study for monitoring my electrocardiogram (EKG).

____

I realize that there is a possibility that I may become seasick during the days in which we are steaming at sea. ________

I am aware that my diet and liberty hours will be strictly controlled and that during dockside and at sea trials my liberty will be curtailed. ________

I am aware that the purpose of this study is to gather important data on the effects of vessel motion, in different sea states, upon crew performance and well being. ________

APPENDIX C

APPENDIX C

POSTEXPERIMENTAL DEBRIEFING QUESTIONNAIRE

Name:______________________________

Subject No.______ Date:____________________

1. Were you assigned or did you volunteer to serve in this experiment?

   Assigned_____ Volunteered_____ Why?______________________________

   ____

2. Which ship motions (roll, pitch, or heave) affected your task performance most and least?

   Most_________________________ Least_________________________

4. Were you sick at any time during the experiment?

   No_____ Yes_____ If yes, were the experimenters aware that you were sick every time you got sick? Yes_____ No_____

5. Did you report each sickness or note it in your log sheets? Yes_____ No_____

6. What was the most meaningful task?______________________________

7. What was the least meaningful task?______________________________

8. What was the most difficult task?______________________________

9. What was the least difficult task?______________________________

10. What task did you like the best?______________________________

11. What task did you like least?______________________________

12. If given the chance, would you serve again in this experiment? No____ Yes____

    Why?____

    Why not?____

13. What would you do to improve the experiment?____________________

    ____

14. What physiological sampling technique was most bothersome?______________

    ____

15. What physiological sampling technique was least bothersome?______________

    ____

Name:______________________________

16. How would you improve upon the physiological sampling techniques?

17. Which adjectives on the check list were most difficult to make decisions about? (Place in order of difficulty)

 1 ______________ 2 ______________ 3 ______________ 4 ______________

18. Which adjectives on the check list were least difficult to make decisions about? (Place in order of ease)

 1 ______________ 2 ______________ 3 ______________ 4 ______________

19. How would you improve upon the check list?

20. On which vessel do you think you performed be. ? (Rank order)

 1 ______________ 2______________ 3 ______________

21. On which vessel did you feel best? (Rank order)

 1 ______________ 2 ______________ 3 ______________

APPENDIX D

APPENDIX D

MOOD AND MOTION SICKNESS SYMPTOMATOLOGY QUESTIONNAIRE

DATE________________________ SUBJECT________________________

WATCH________________________

MOOD AND MOTION QUESTIONNAIRE

Mood Questionnaire

1. angry — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
2. clutched up — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
3. carefree — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
4. elated — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
5. concentrating — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
6. drowsy — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
7. affectionate — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
8. regretful — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
9. dubious — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
10. boastful — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
11. active — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________
12. defiant — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks________________

MOOD AND MOTION QUESTIONNAIRE

13. fearful — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

14. playful — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

15. overjoyed — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

16. engaged in thought — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

17. sluggish — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

18. kindly — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

19. sad — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

20. skeptical — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

21. egotistic — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

22. energetic — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

23. rebellious — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

24. jittery — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

25. witty — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

26. pleased — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

27. intent — Definitely_____ Slightly_____ Undecided_____ Definitely NOT_____ Remarks_____

MOOD AND MOTION QUESTIONNAIRE

28. tired — Definitely_____ Slightly_____ Undecided_____
Definitely NOT_____ Remarks_____________________

29. warmhearted — Definitely_____ Slightly_____ Undecided_____
Definitely NOT_____ Remarks_____________________

30. sorry — Definitely_____ Slightly_____ Undecided_____
Definitely NOT_____ Remarks_____________________

31. suspicious — Definitely_____ Slightly_____ Undecided_____
Definitely NOT_____ Remarks_____________________

32. self-centered — Definitely_____ Slightly_____ Undecided_____
Definitely NOT_____ Remarks_____________________

33. vigorous — Definitely_____ Slightly_____ Undecided_____
Definitely NOT_____ Remarks_____________________

Motion Questionnaire

1. general discomfort — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

2. fatigue — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

3. boredom — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

4. mental depression — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

5. drowsiness — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

6. headache — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

7. "fullness of the head" — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

8. blurred vision — None_____ Slight_____ Moderate_____ Severe_____
Remarks_____________________

MOOD AND MOTION QUESTIONNAIRE

9.	a.	dizziness with eyes open	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
	b.	dizziness with eyes closed	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
10.		loss of direction	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
11.	a.	salivation increased	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
	b.	salivation decreased	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
12.		sweating	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
13.		faintness	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
14.		aware of breathing	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
15.		stomach upset	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
16.		nausea	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
17.		burping	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
18.		loss of appetite	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
19.		increased appetite	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
20.		desire to move bowels	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____
21.		vomiting	None_____ Slight_____ Moderate_____ Severe_____ Remarks_____

MOOD AND MOTION QUESTIONNAIRE

22.	confusion	None____ Slight____ Moderate____ Severe____ Remarks__________
23.	apathetic	None____ Slight____ Moderate____ Severe____ Remarks__________
24.	queasy	Yes____ No____ Remarks__________
25.	relaxed	Yes____ No____ Remarks__________
26.	clammy	Yes____ No____ Remarks__________
27.	yawning	Often____ Occasionally____ None____ Remarks__________
28.	smoking more than usual	Yes____ No____ Remarks__________
29.	physically tired	Very____ Somewhat____ No____ Remarks__________
30.	mentally tired	Very____ Somewhat____ No____ Remarks__________
31.	crave certain foods	Yes____ No____ Type__________
32.	claustrophobic	Yes____ No____ Remarks__________
33.	bothered by personal habits of partner	Yes____ No____ Remarks__________
34.	irritable	Very____ Somewhat____ No____ Remarks__________

APPENDIX E

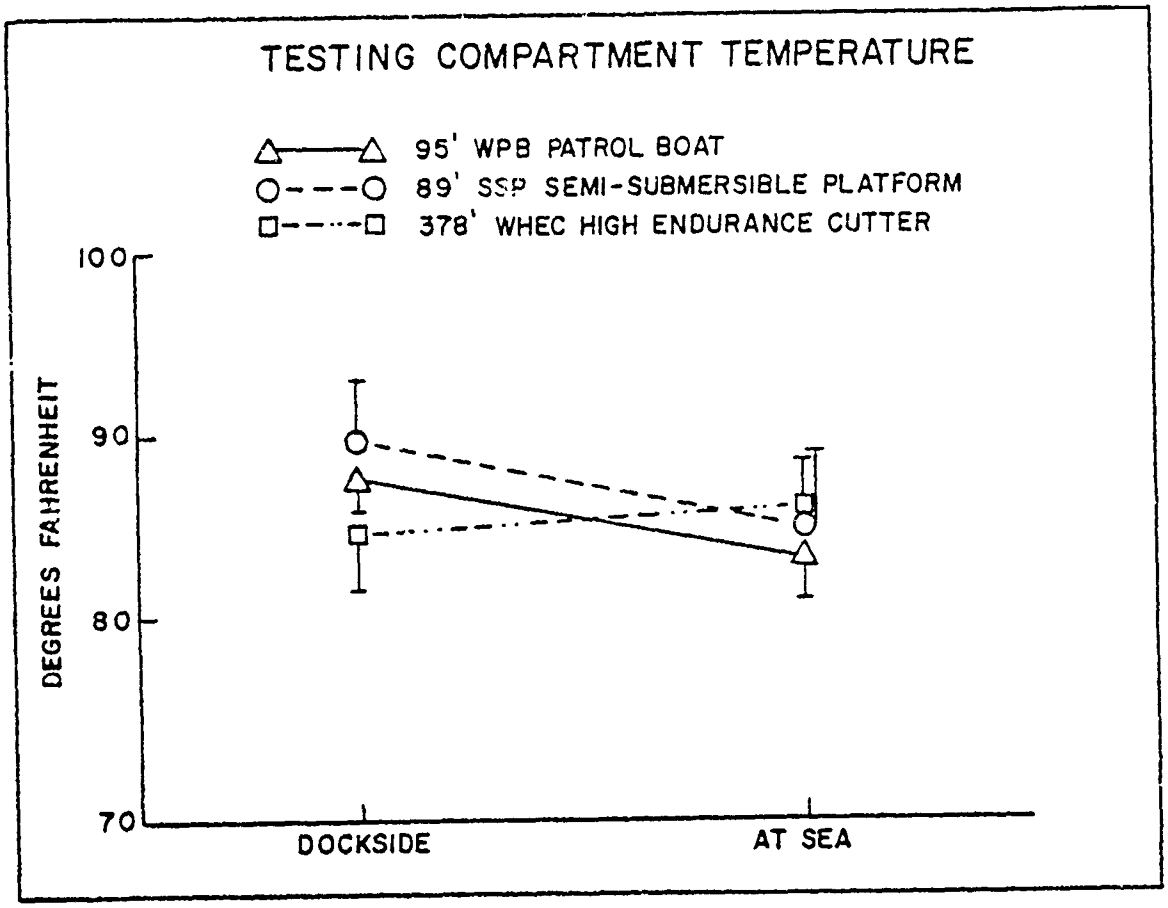

FIGURE E-1: Mean response and standard error of test compartment temperature as a function of vessel class and testing condition.

Test Compartment Temperature (F°)	Dockside $\bar{x} \pm SE$	At Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
95' WPB	87.4 ± 1.6	83.3 ± 1.6	.58	Treatment Residual	264 361	1 95	264 3.7	69.5 ***
89' SSP	89.9 ± 3.7	85.0 ± 3.7	.30	Treatment Residual	563 1297	1 95	563 13.7	41.2 ***
378' WHEC	84.5 ±	85.3 ± 2.9	.02	Treatment Residual	17 820	1 95	17 8.6	2.[illegible]

*** $p < .001$

TABLE E-1: Comparisons of test compartment temperatures for vessels between dockside and at sea conditions.

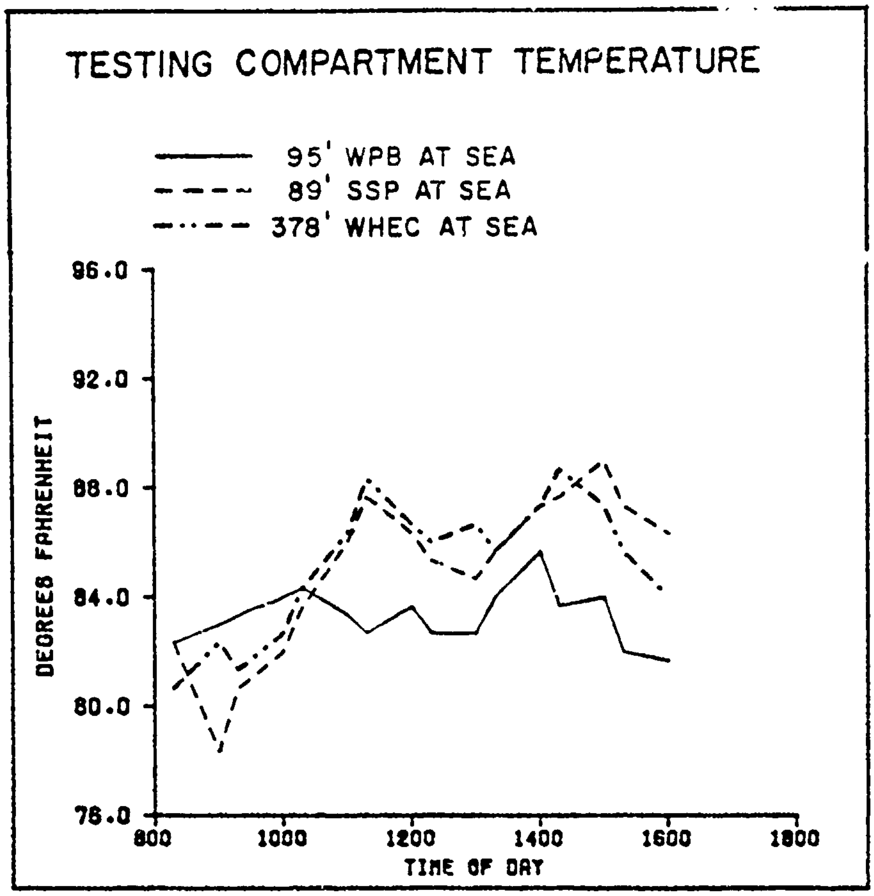

FIGURE E-2: Average testing compartment dry bulb temperature aboard each vessel at sea.

WPB $\bar{x} \pm SE$	SSP $\bar{x} \pm SE$	WHEC $\bar{x} \pm SE$	R^2
83.3 ± 3.2	85.0 ± 3.2	85.3 ± 3.2	.08

Source	SS	df	MS	F
Vessels	12	2	6	3.5*
Residual	160	94	1.7	
Total	172	96		

* $p < .05$

TABLE E-2: Comparisons of vessel test compartment temperatures at sea.

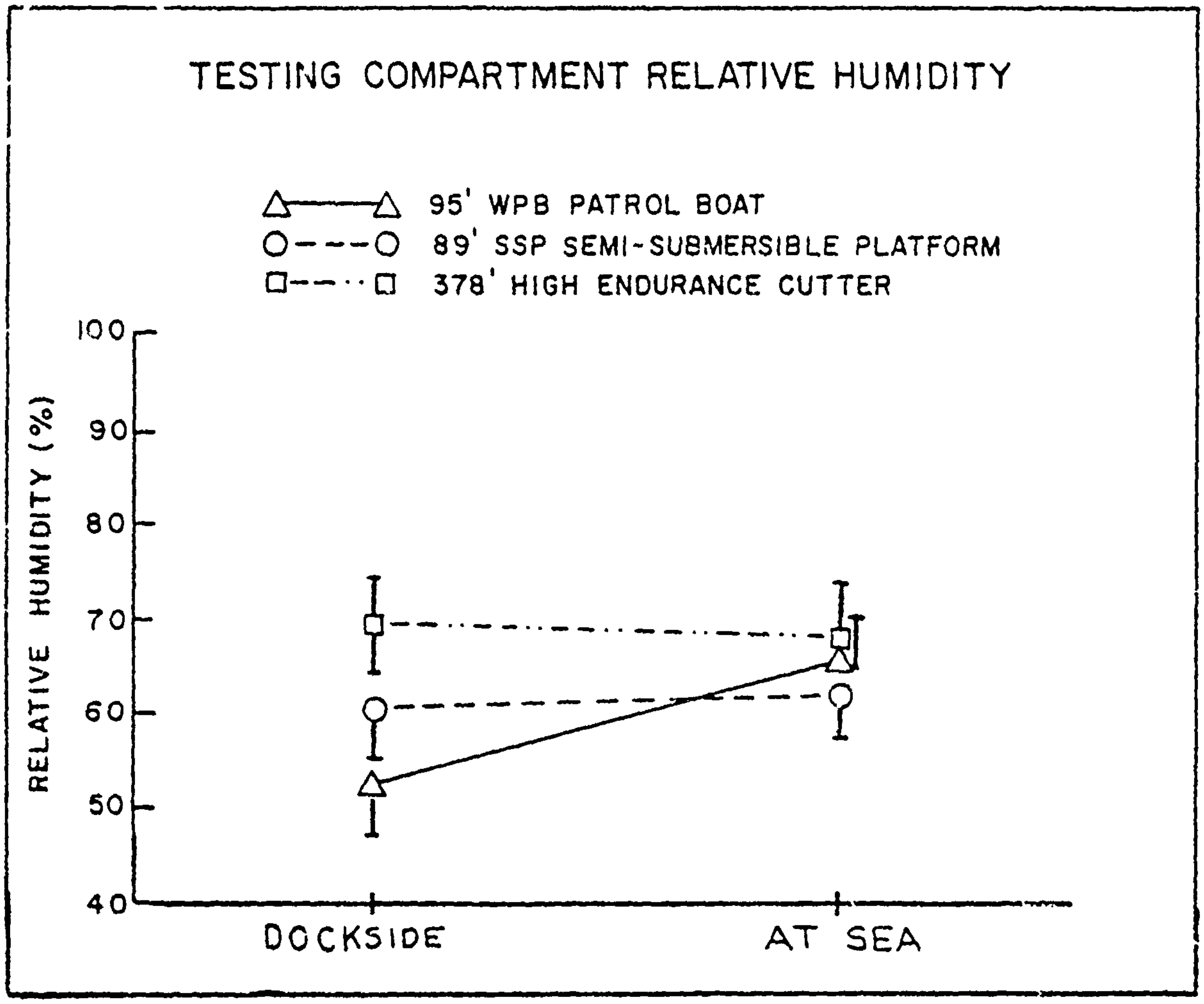

FIGURE E-3: Mean response and standard error of test compartment relative humidity as a function of vessel class and testing condition.

Test Compartment Humidity	Dockside $\bar{x} \pm SE$	At Sea $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
95' WPB	56.6 ± 5.5	65.5 ± 5.5	.35	Treatment Residual	1728 3237	1 95	1728 34	50.7 ***
89' SSP	60.6 ± 6.3	67.2 ± 6.3	.10	Treatment Residual	1013 8879	1 95	1013 93.4	10.8 ***
378' WHEC	69.0 ± 7.2	67.7 ± 7.2	.01	Treatment Residual	39 3834	1 95	39 40	0.97

*** p < .001

TABLE E-3: Comparisons of test compartment relative humidities of all vessels between dockside and at sea conditions.

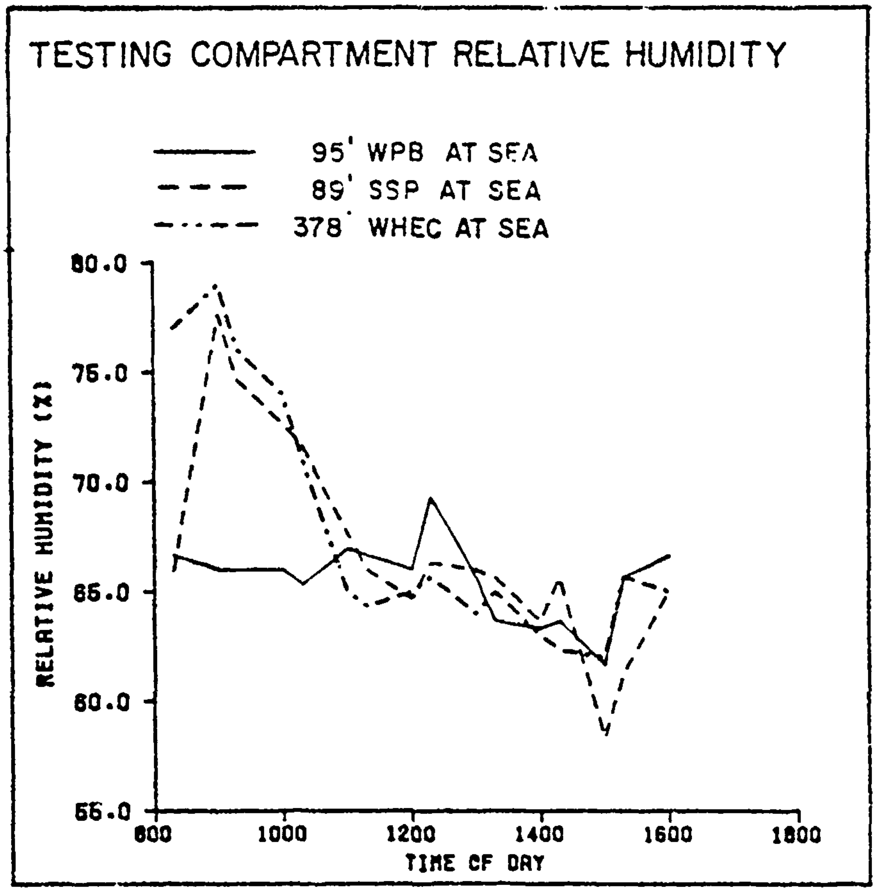

FIGURE E-4: Average test compartment relative humidity aboard each vessel at sea.

WPB $\bar{x} \pm SE$	SSP $\bar{x} \pm SE$	WHEC $\bar{x} \pm SE$	R^2	Source	SS	df	MS	F
65.5 ± 6.1	67.2 ± 6.1	67.7 ± 6.1	.02	Vessels Residual	122 5280	2 142	61 37	1.6
				Total	5402	144		

TABLE E-4: Comparisons of vessel test compartment relative humidities at sea.

APPENDIX F

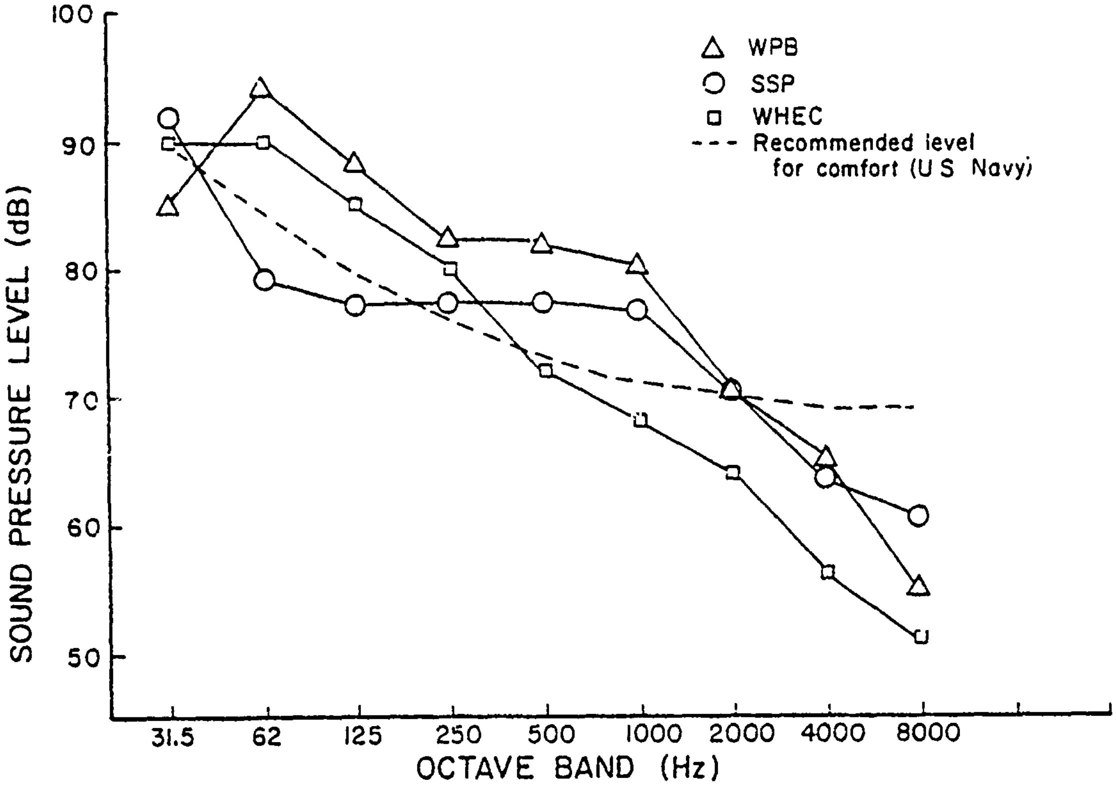

FIGURE F-1--Sound pressure levels in vessel testing compartments.

Source	SS	df	MS	F
Vessels Residual	114.7 3509.3	2 24	57.37 146.22	0.39
Total	3624	26		

TABLE F-1--Comparisons of vessel test compartment sound pressure levels at sea.

APPENDIX G

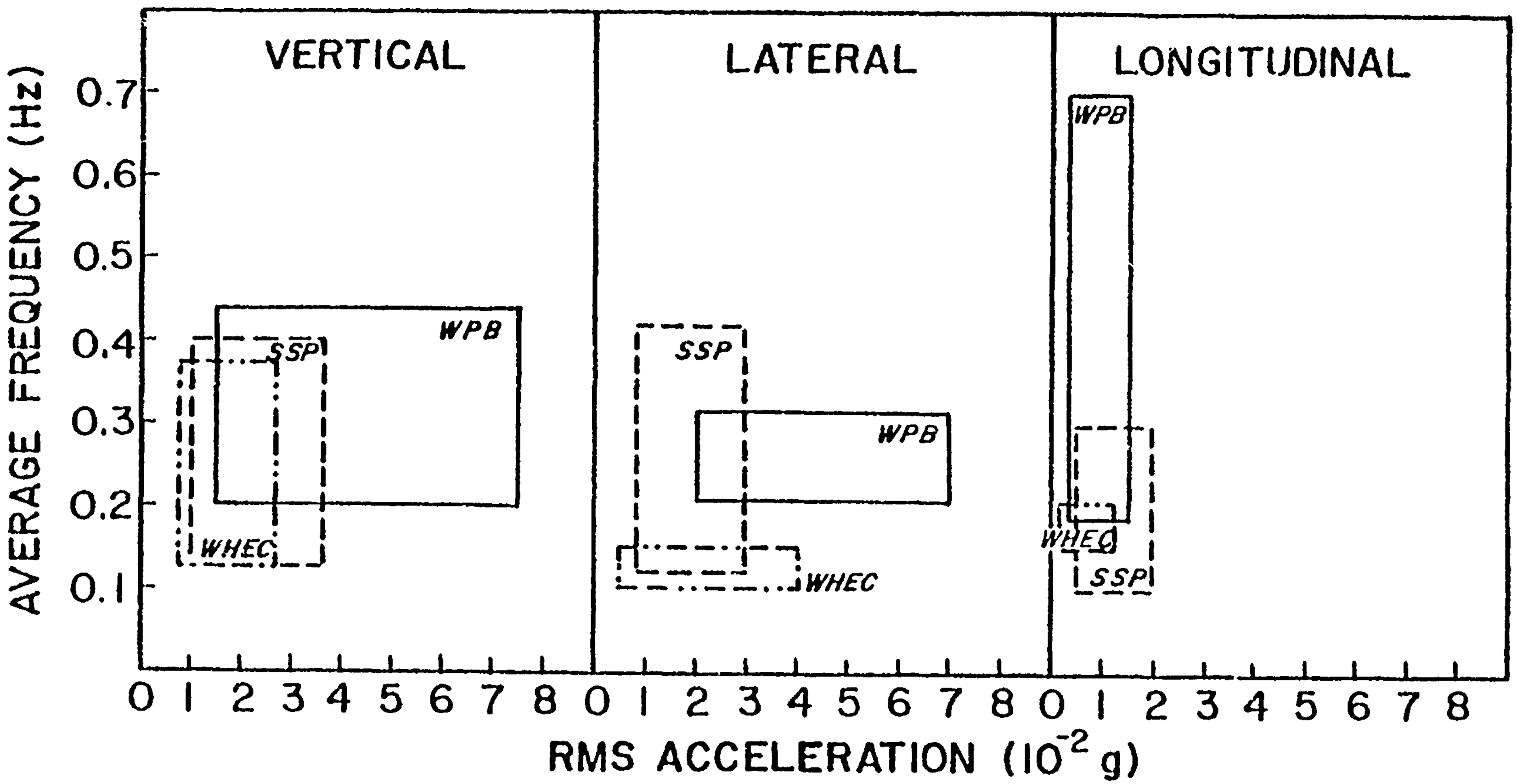

Fig. G-1 **AVERAGE FREQUENCY AND RMS ACCELERATION RANGES PER VESSEL CLASS**

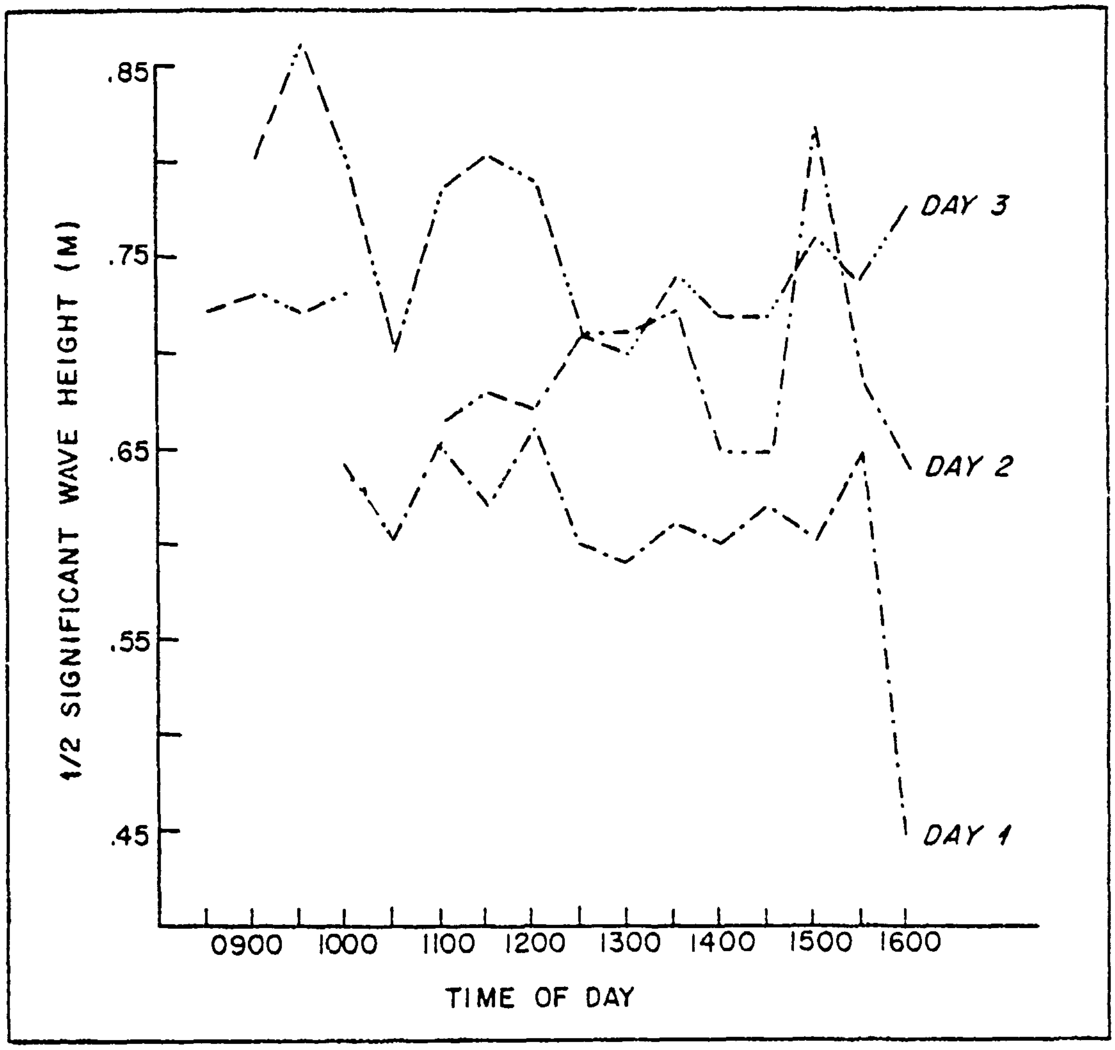

Fig. G-2. Wave height plotted across steaming days.

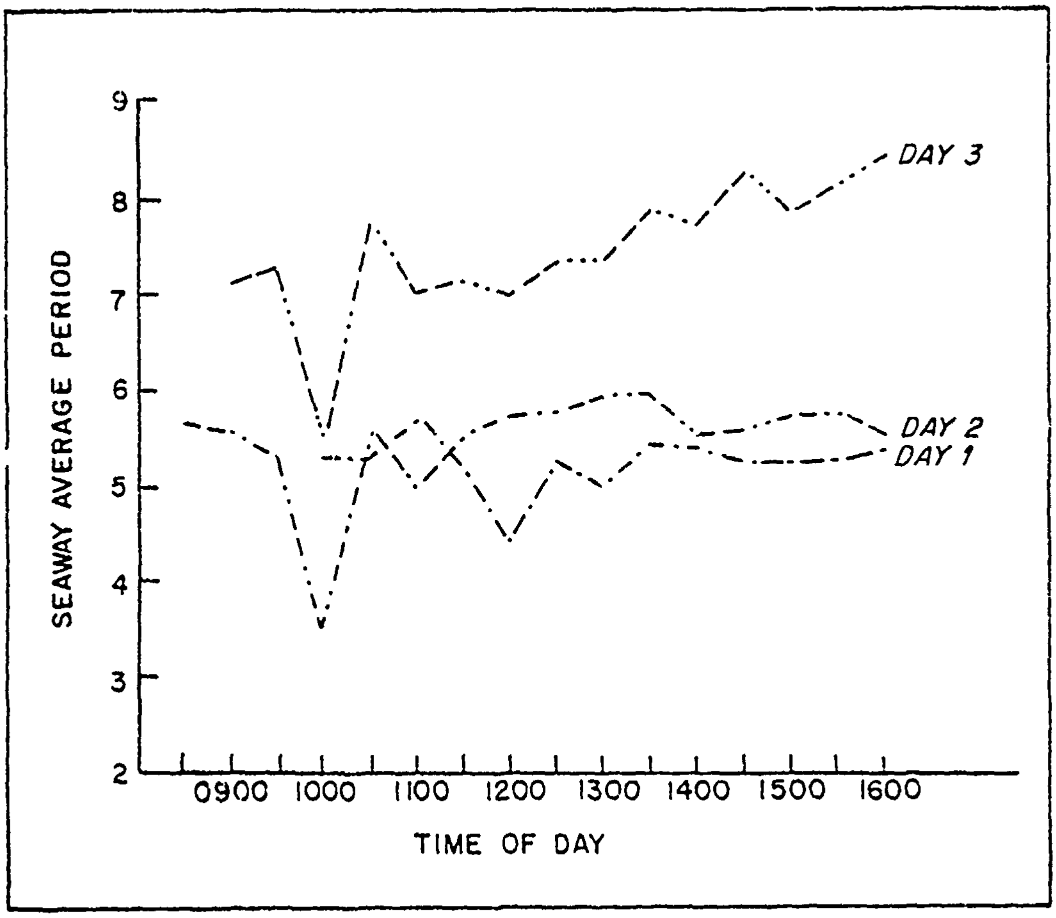

Fig. G-3. Swell average period plotted across steaming days.

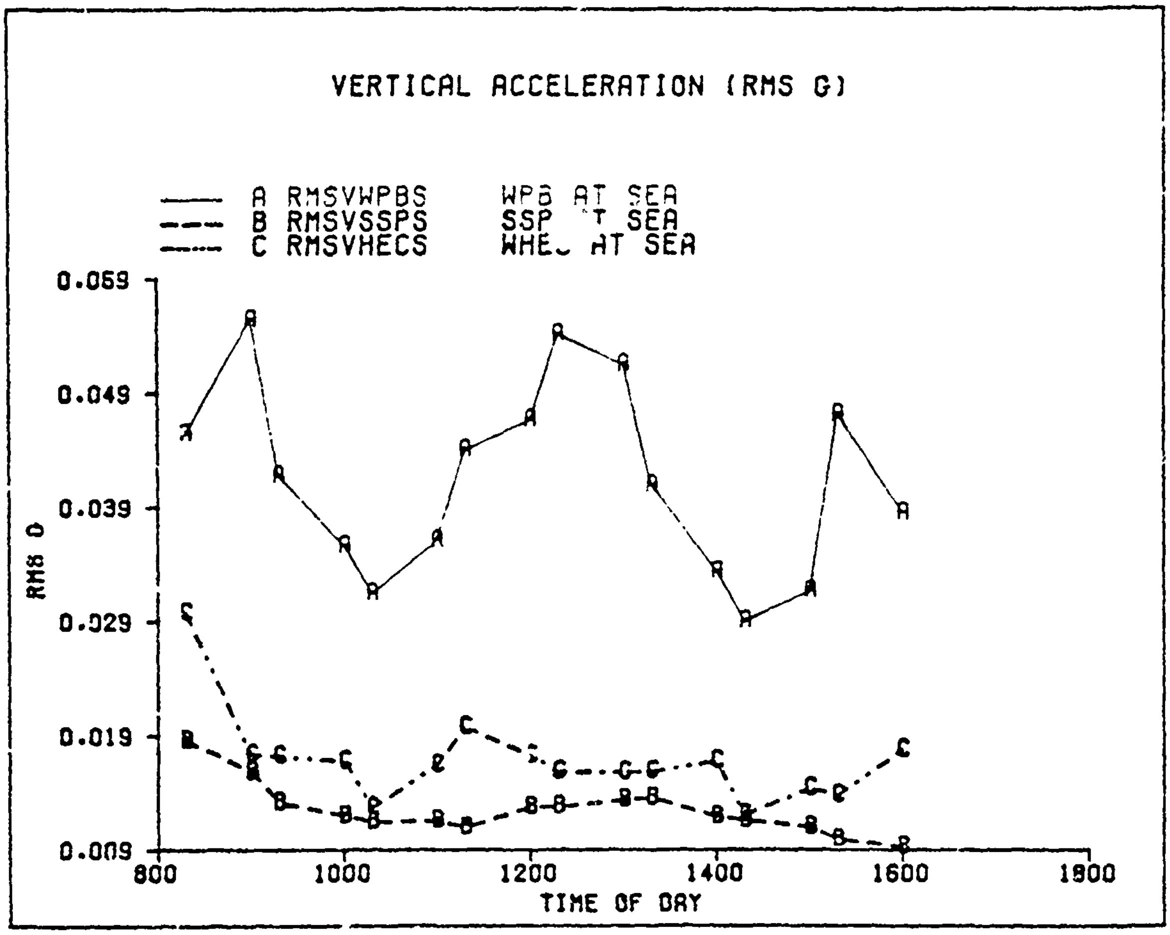

Fig. G-4. Average single amplitude vertical accelerations aboard each vessel during steaming days.

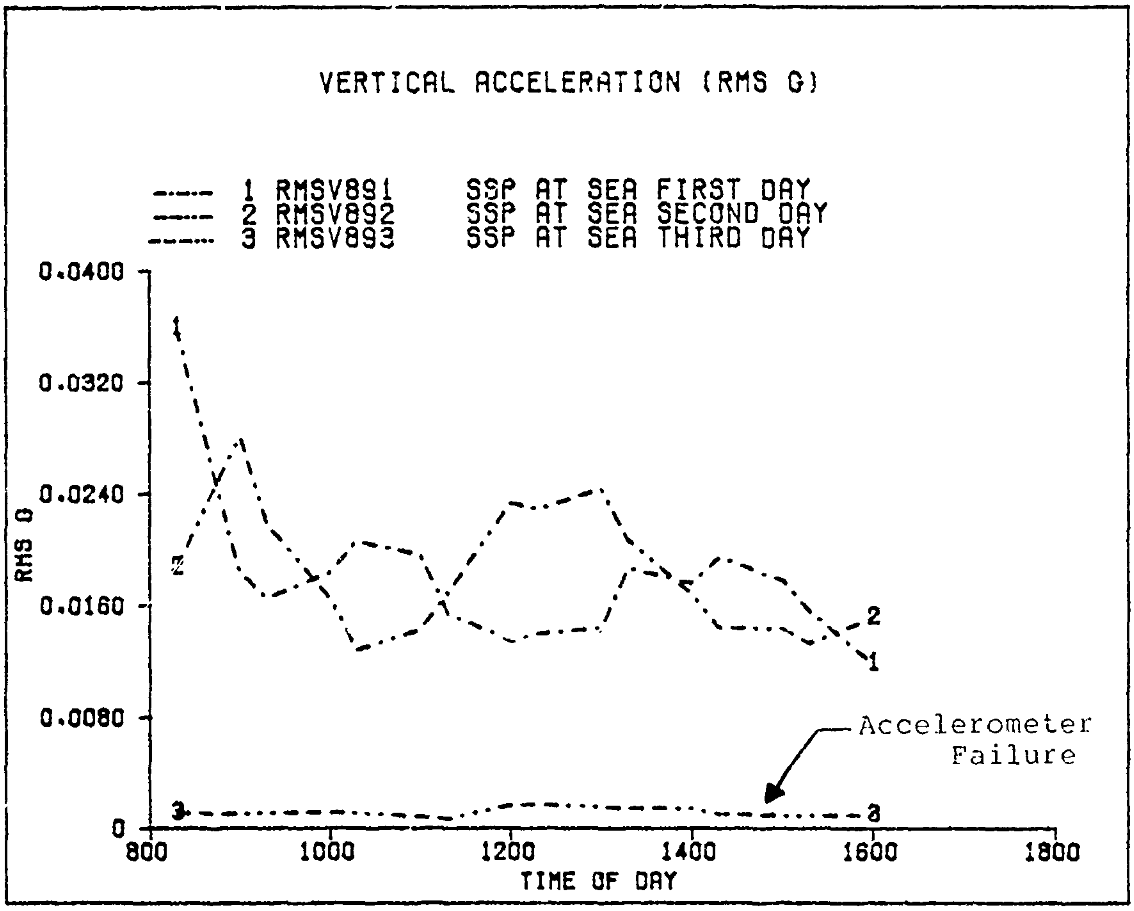

Fig. G-5. Vertical single amplitude accelerations aboard the SSP during the three steaming days.

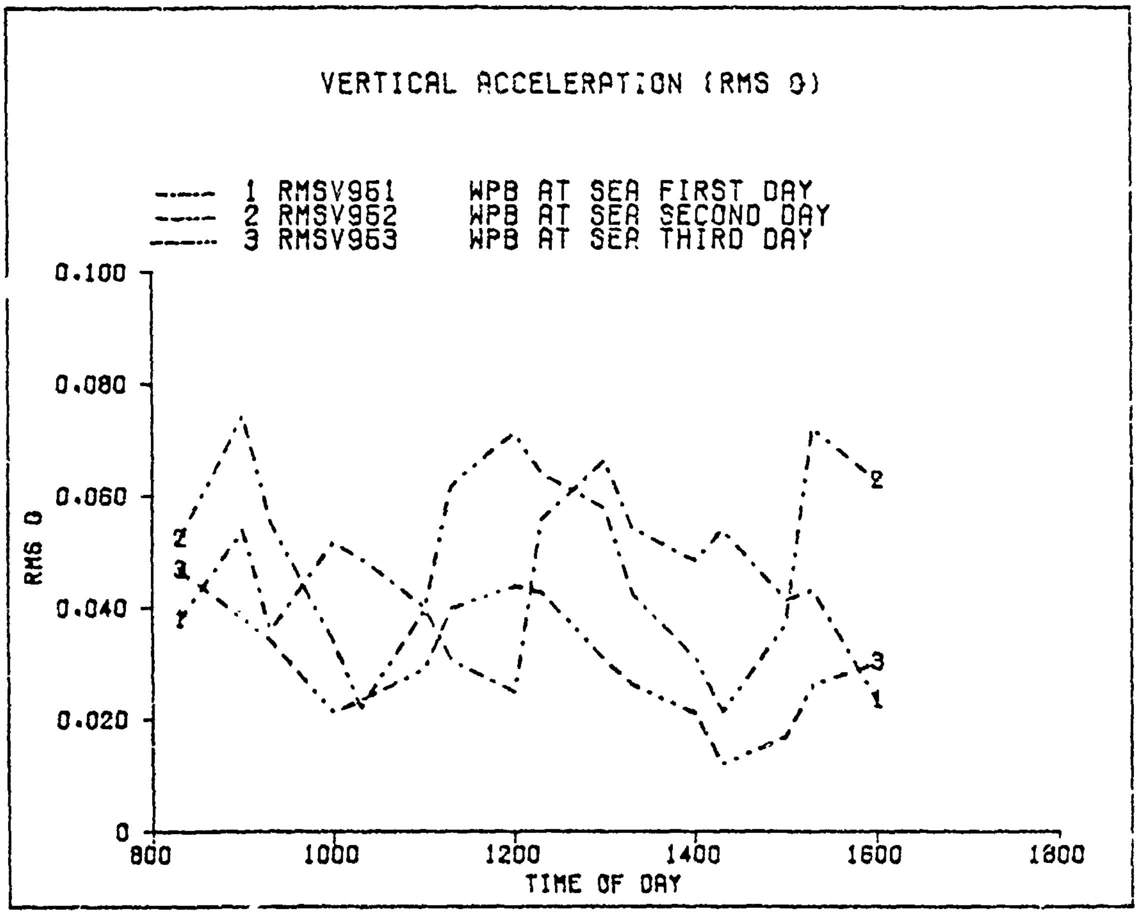

Fig. G-6. Vertical single amplitude accelerations aboard the WPB during the three steaming days.

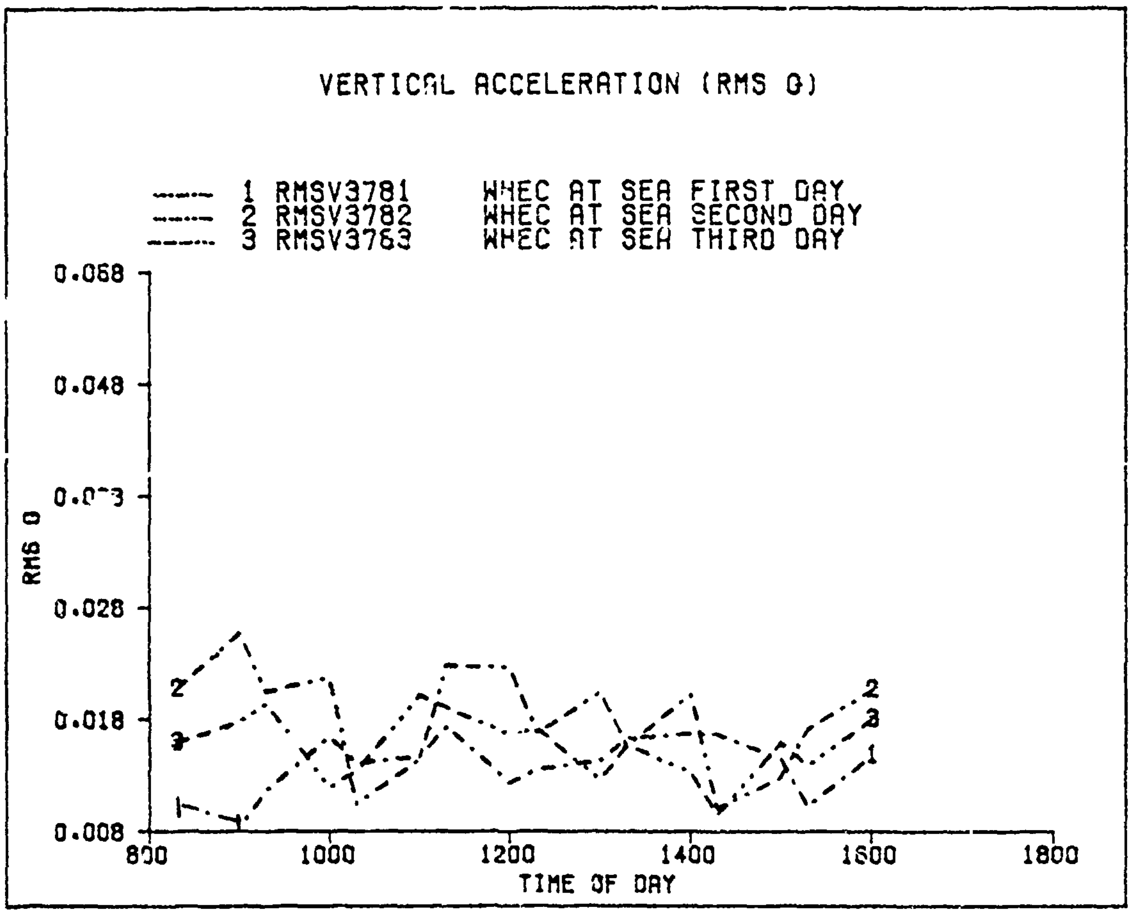

Fig. G-7. Vertical single amplitude accelerations aboard the WHEC during the three steaming days.

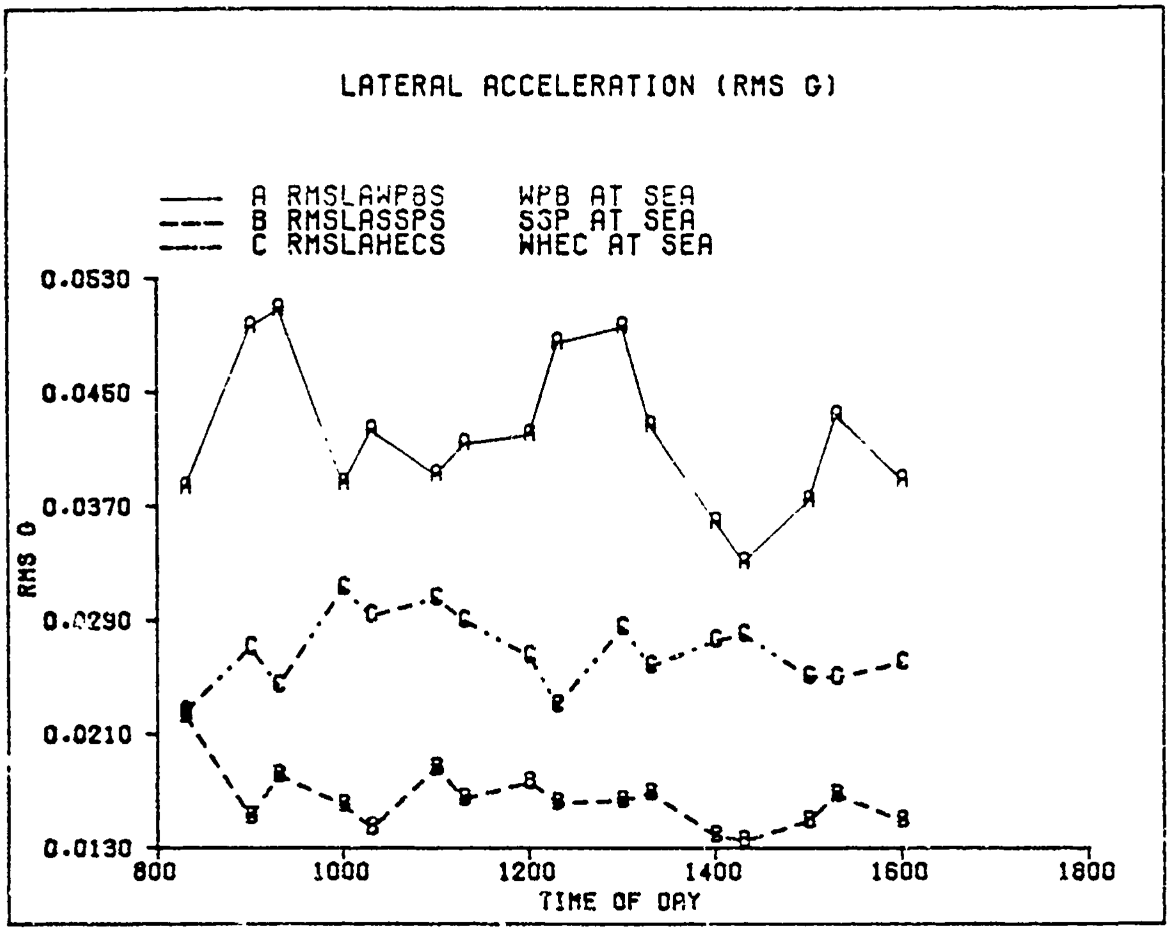

Fig. G-8. Average single amplitude lateral accelerations aboard each vessel during steaming days.

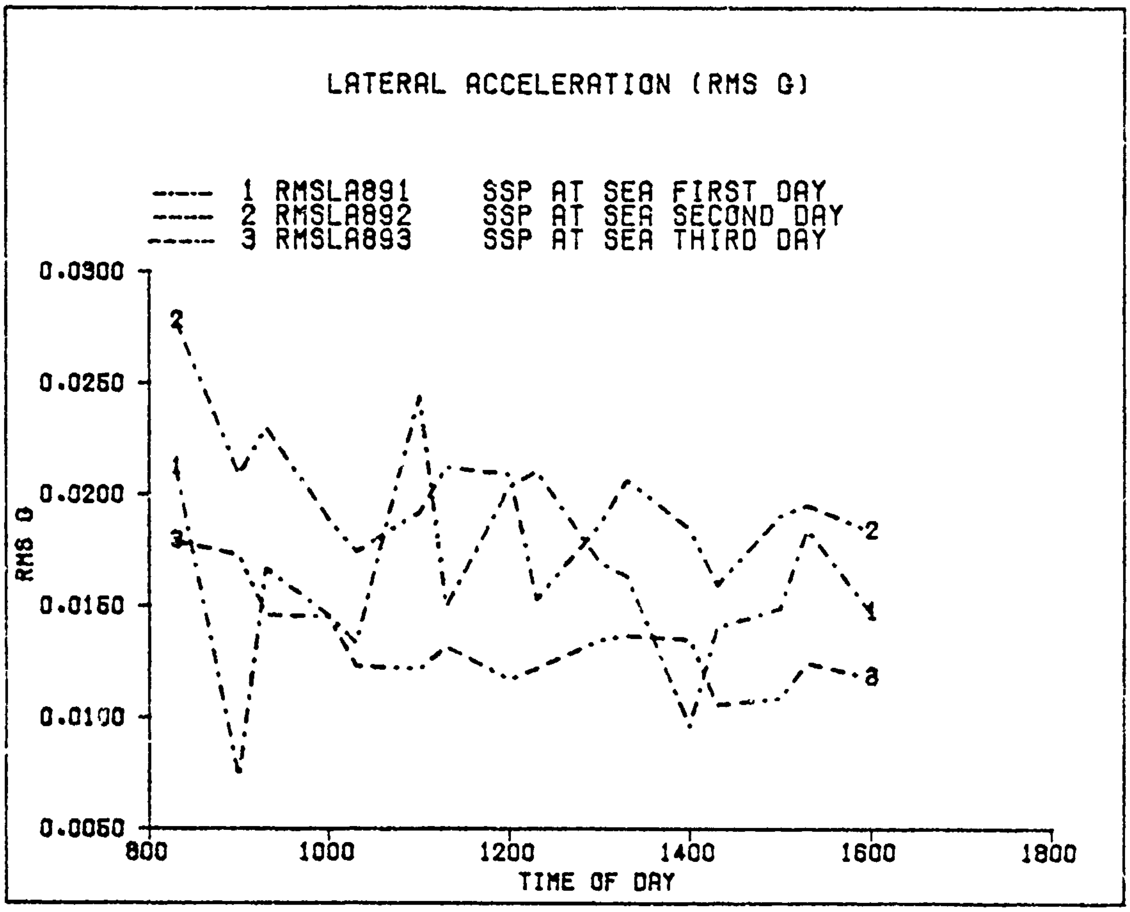

Fig. G-9. Lateral single amplitude accelerations aboard the SSP during the three steaming days.

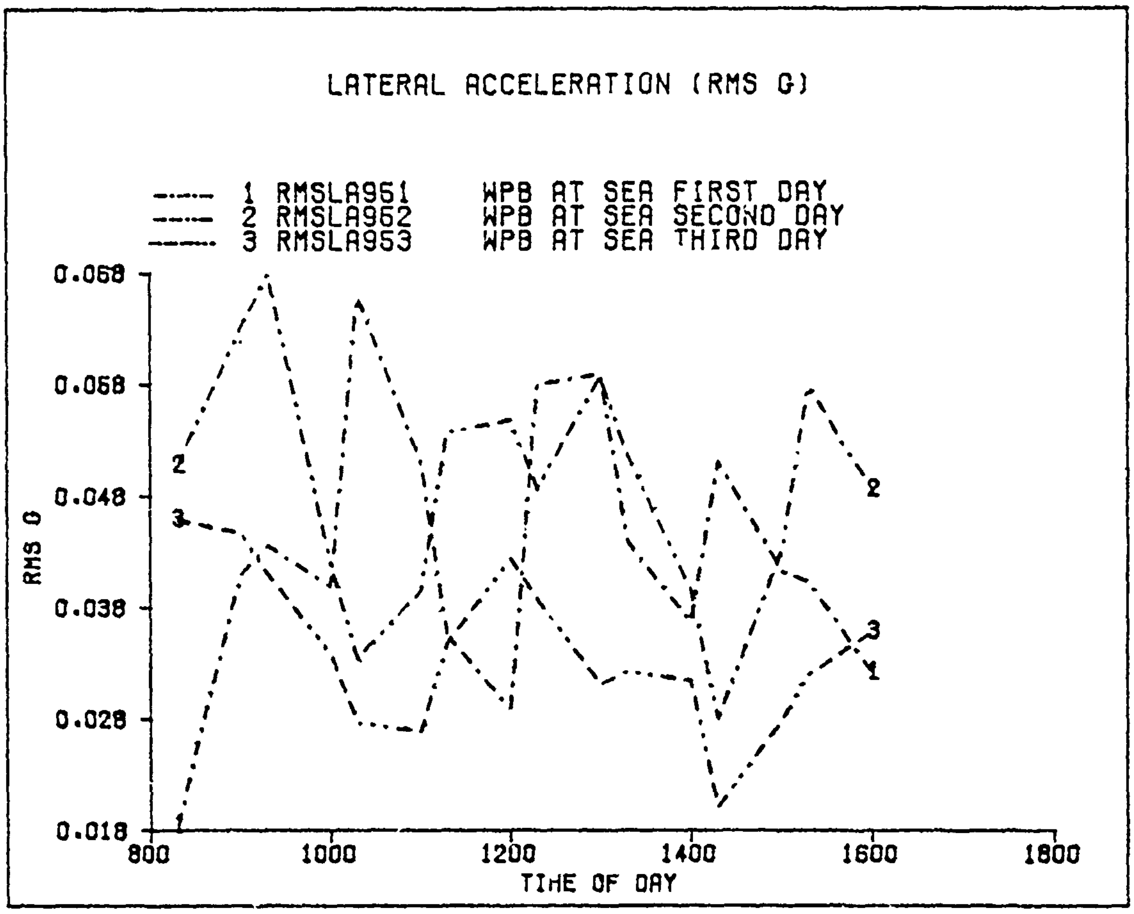

Fig. G-10. Lateral single amplitude accelerations aboard the WPB during the three steaming days.

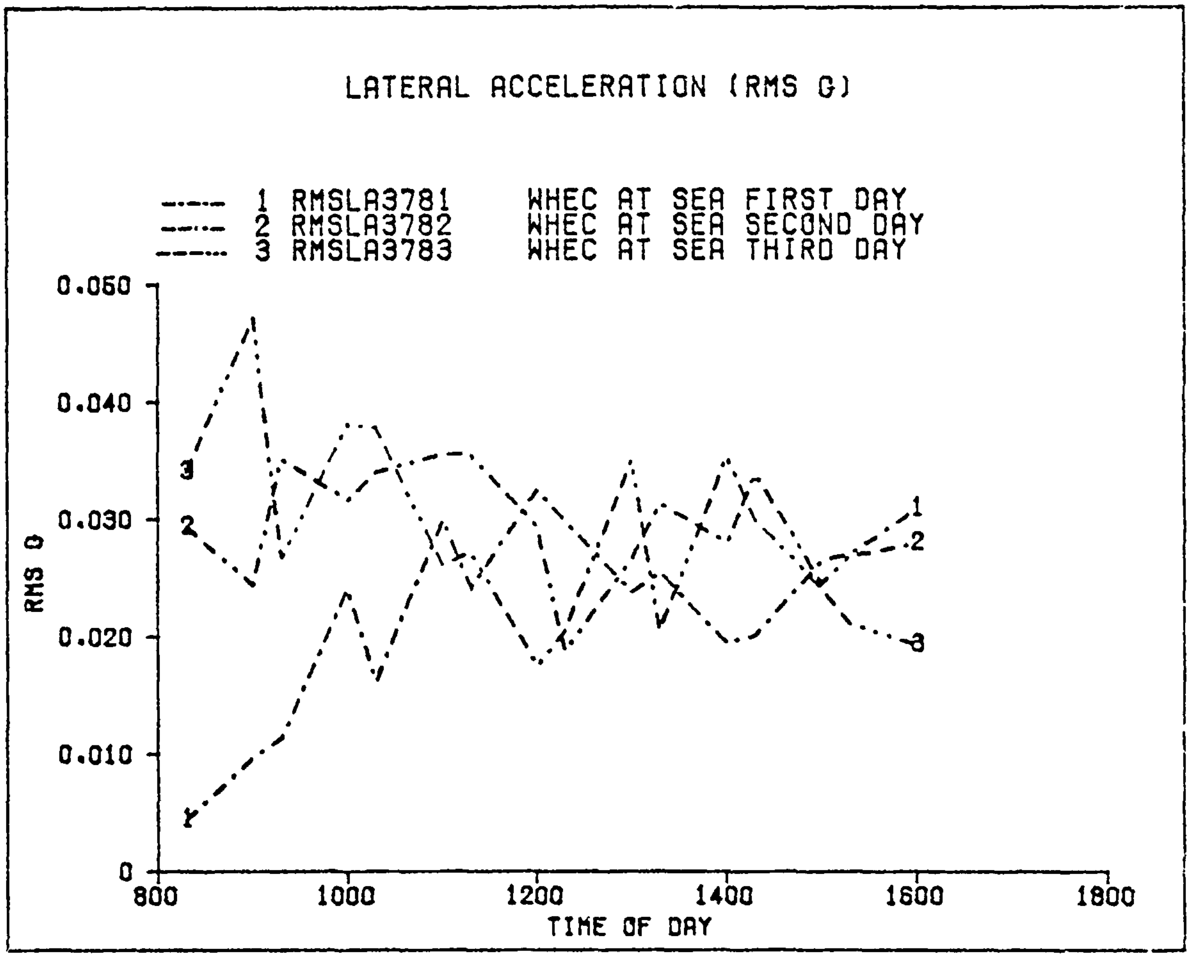

Fig. G-11. Lateral single amplitude accelerations aboard the WHEC during the three steaming days.

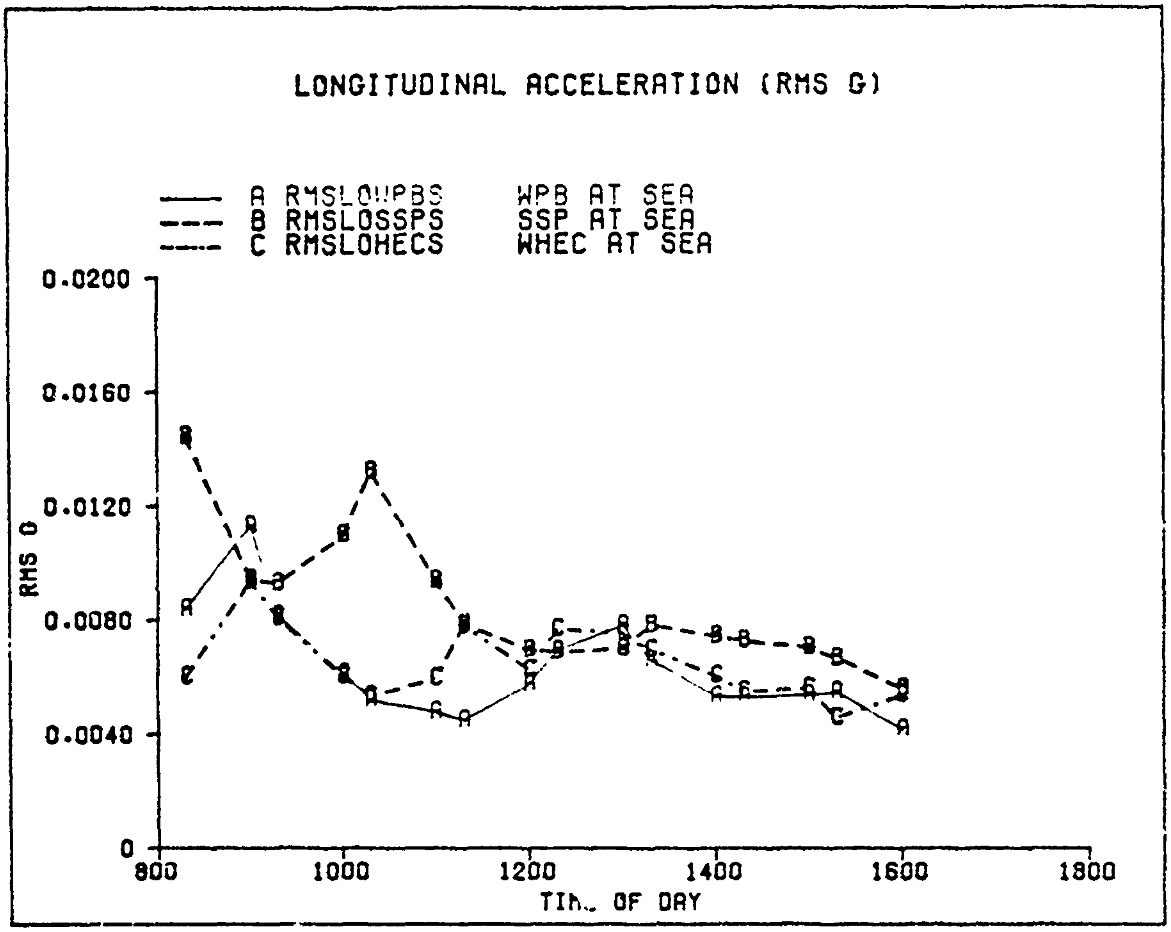

Fig. G-12. Average single amplitude longitudinal accelerations aboard each vessel during steaming days.

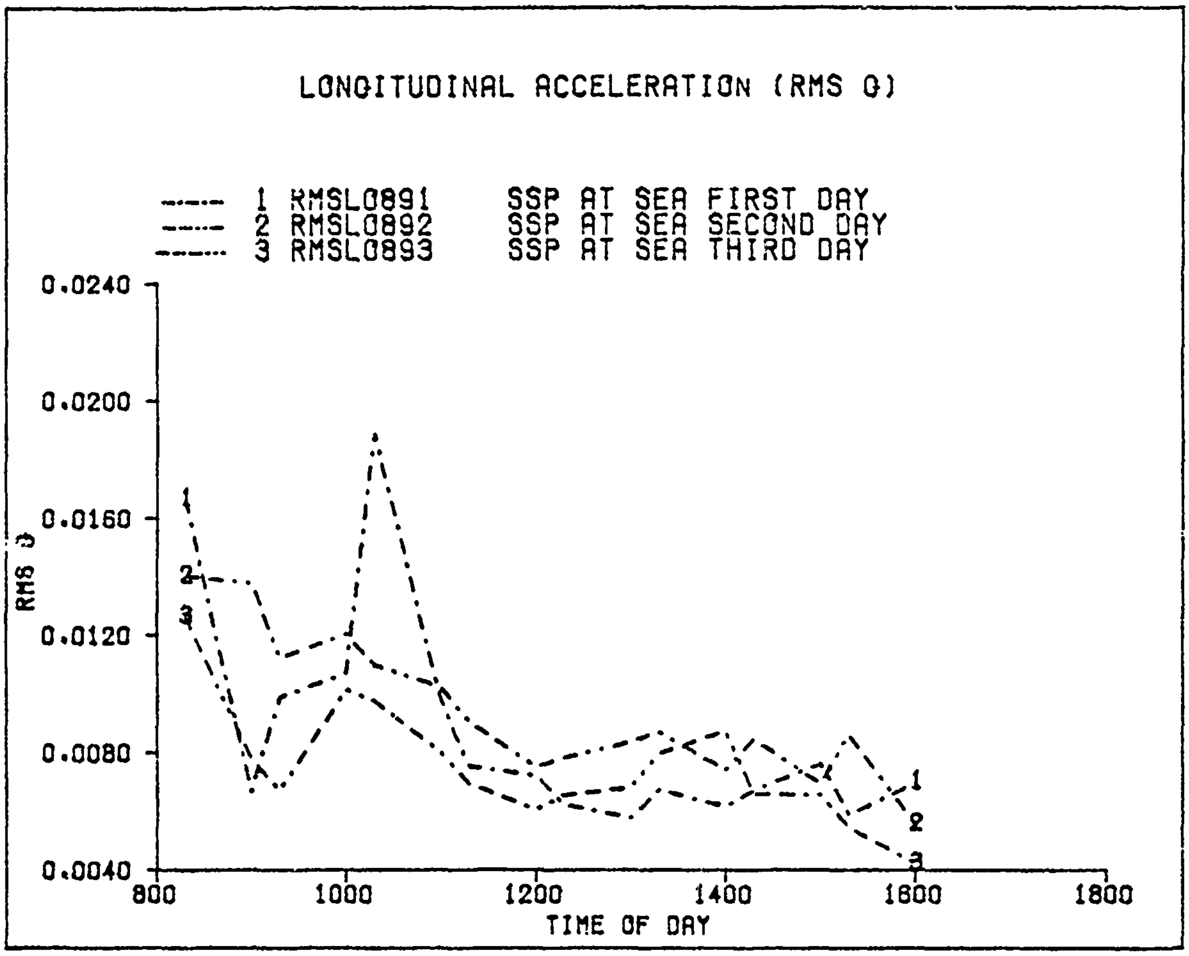

Fig. G-13. Longitudinal single amplitude accelerations aboard the SSP during the three steaming days.

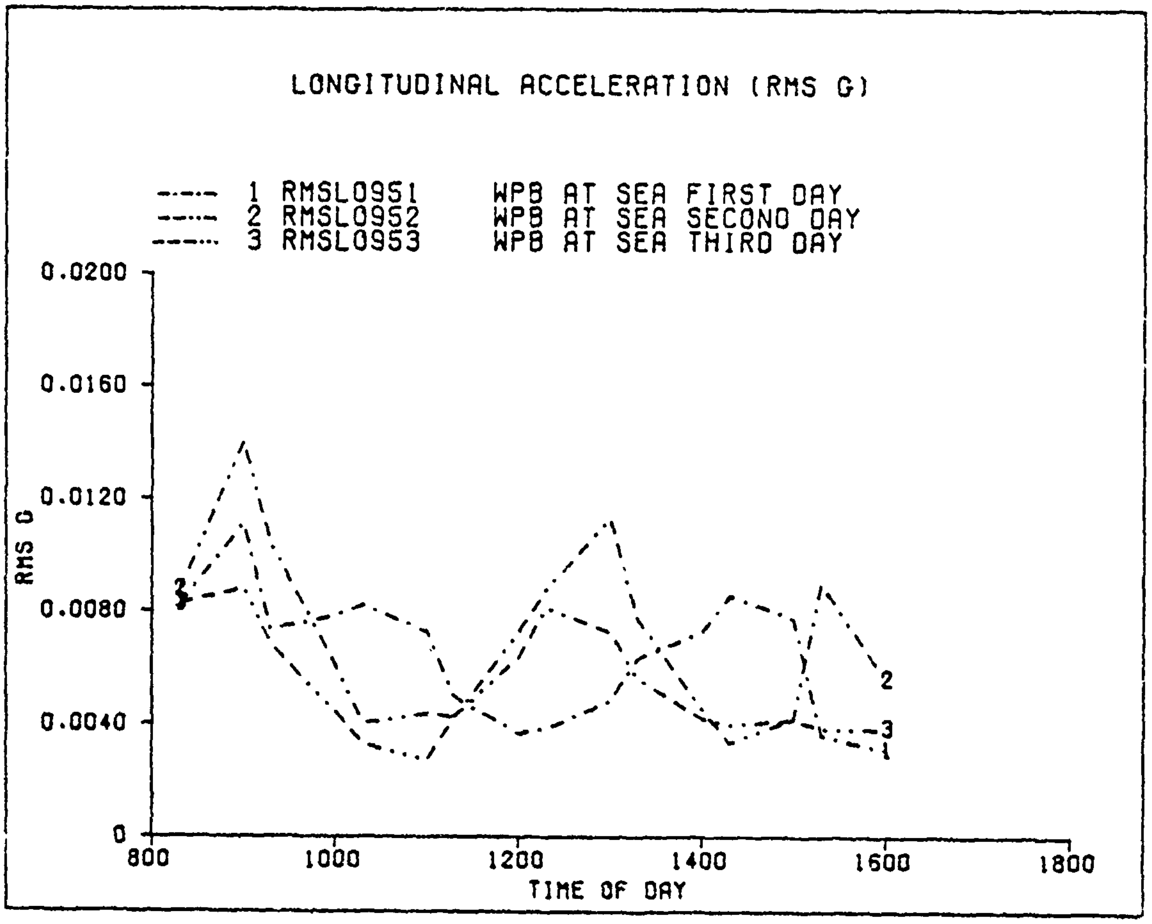

Fig. G-14. Longitudinal single amplitude accelerations aboard the WPB during the three steaming days.

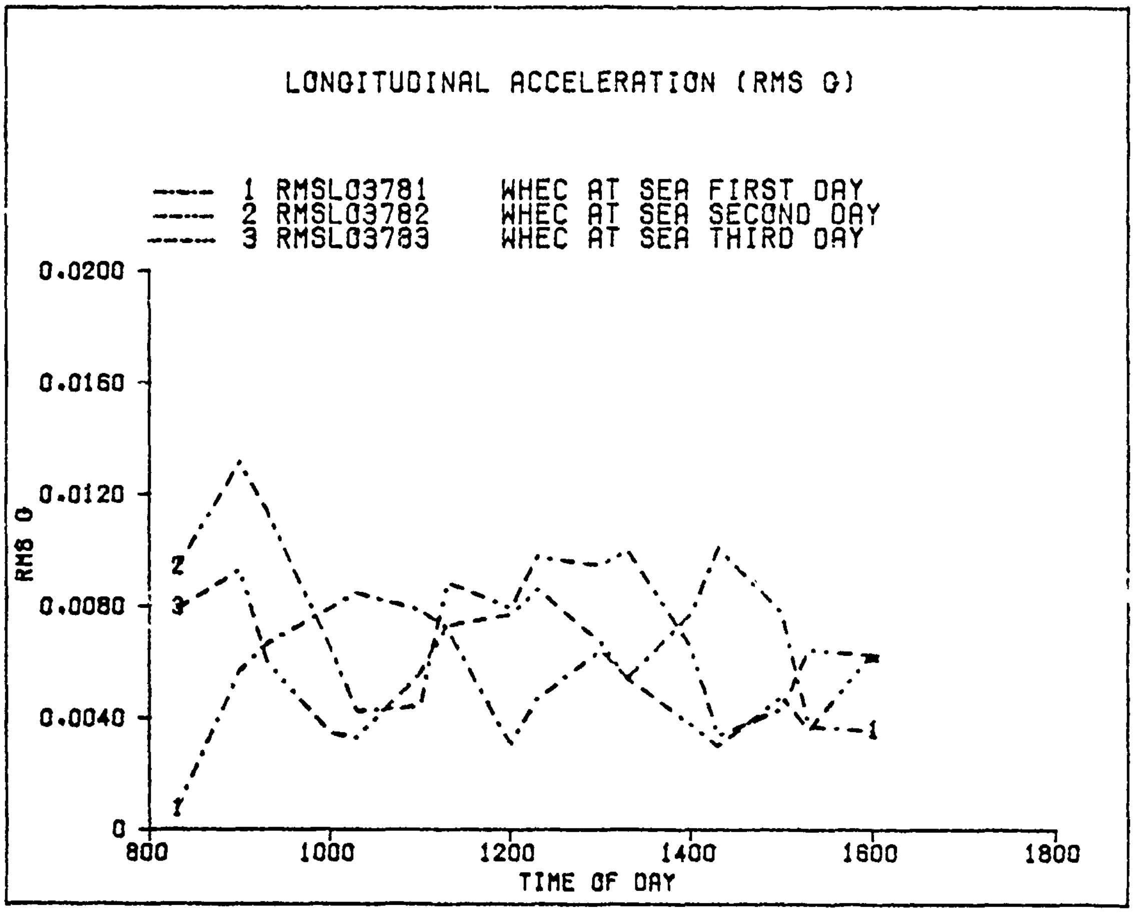

Fig. G-15. Longitudinal single amplitude accelerations aboard the WHEC during the three steaming days.

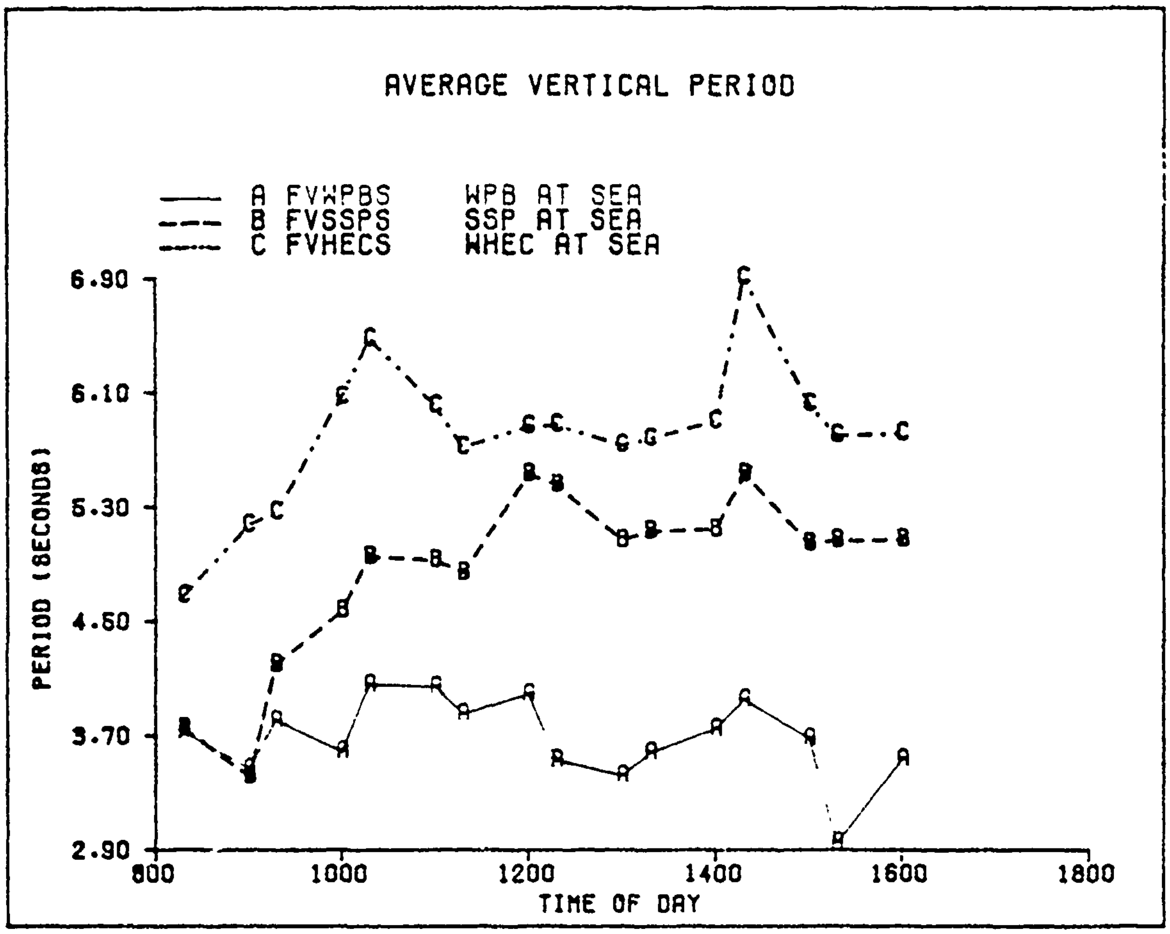

Fig. G-16. Average periods of vertical motions aboard each vessel during the three steaming days.

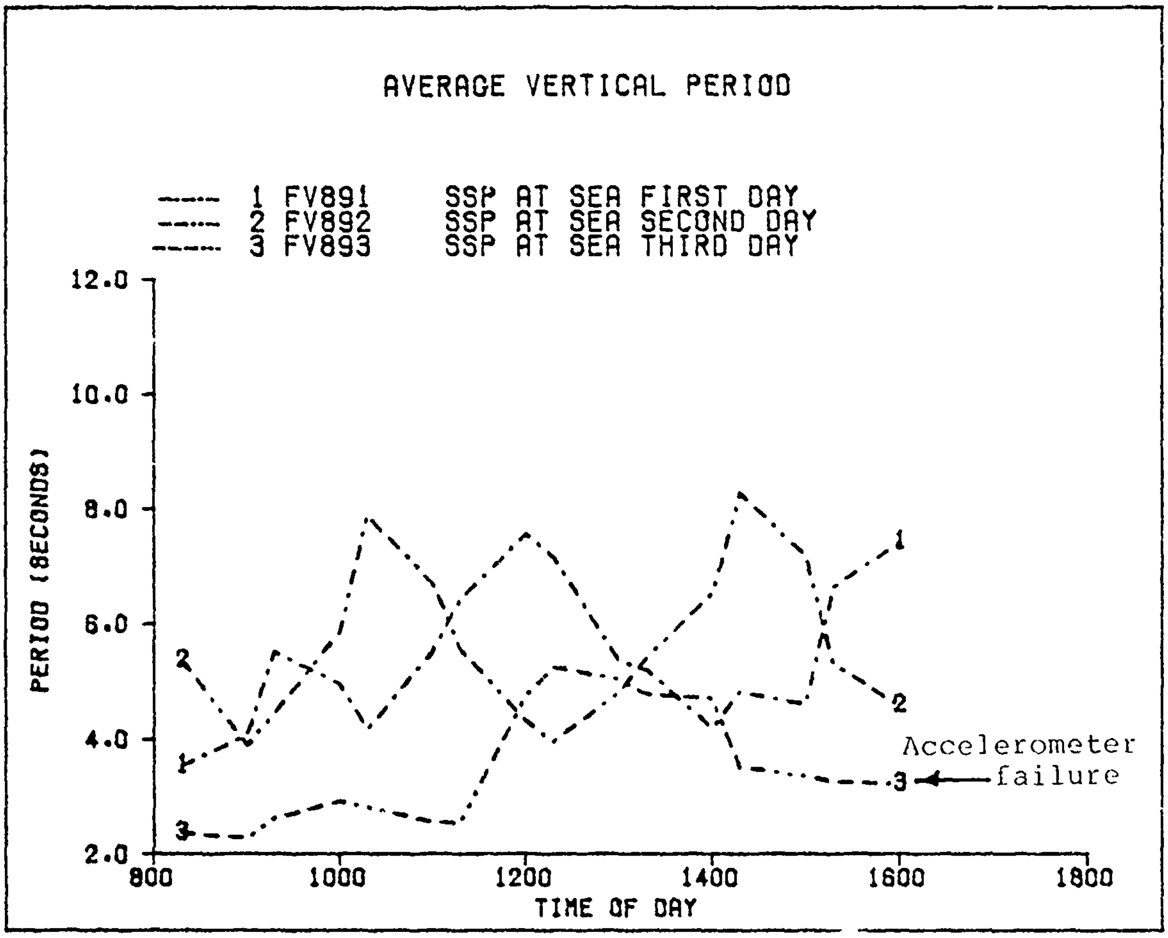

Fig. G-17. Periods of vertical motions aboard the SSP during the three steaming days.

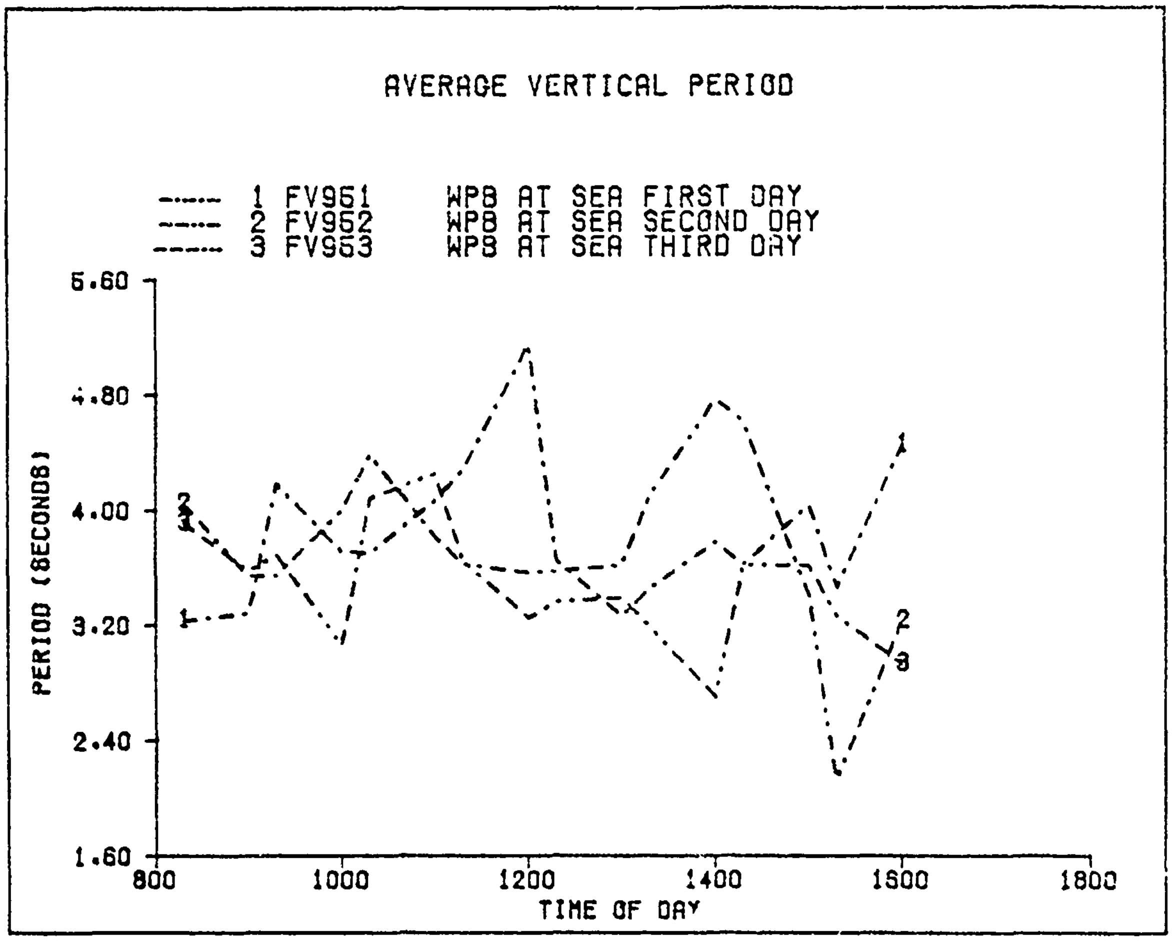

Fig. G-18. Periods of vertical motions aboard the WPB during the three steaming days.

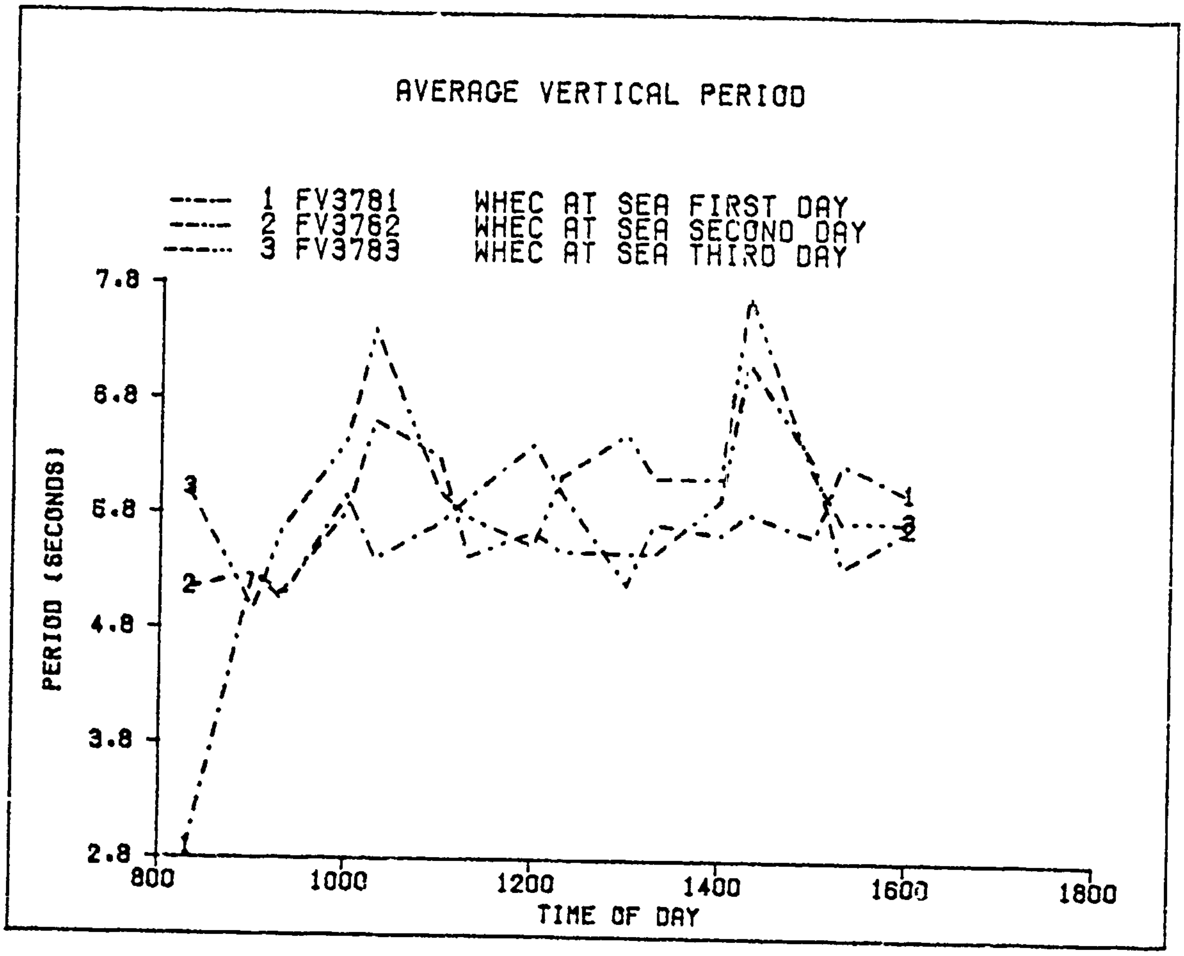

Fig. G-19. Periods of vertical motions aboard the WHEC during the three steaming days.

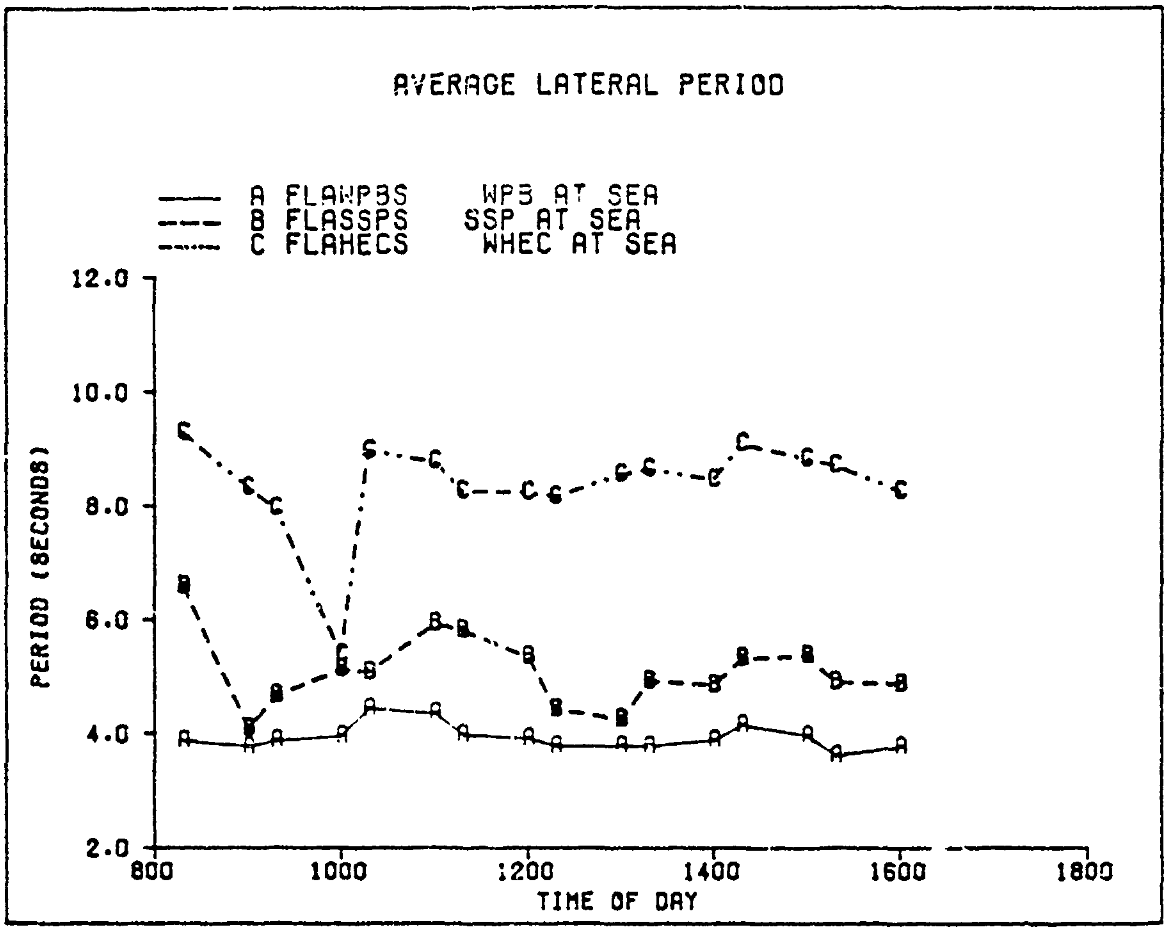

Fig. G-20. Average periods of lateral motions aboard each vessel during the three steaming days.

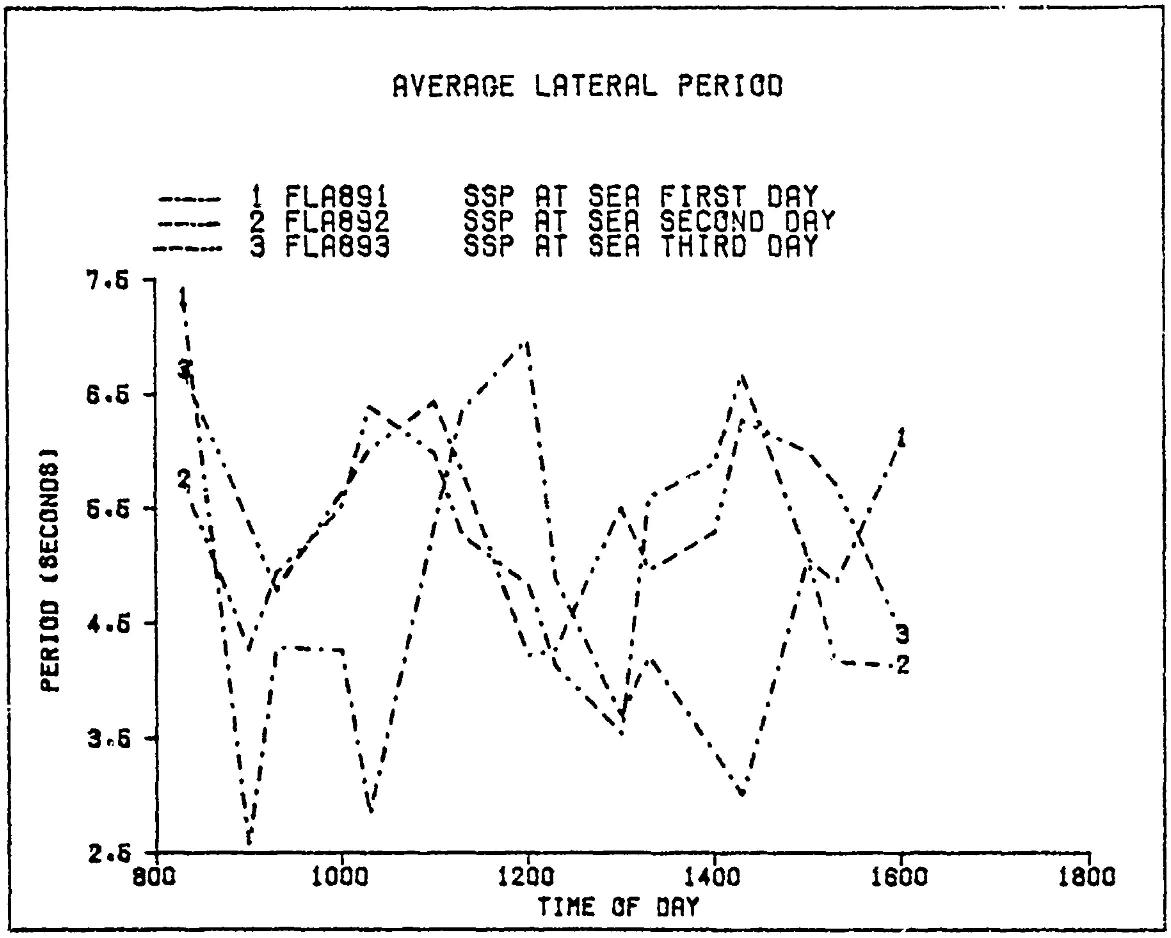

Fig. G-21. Periods of lateral motions aboard the SSP during the three steaming days.

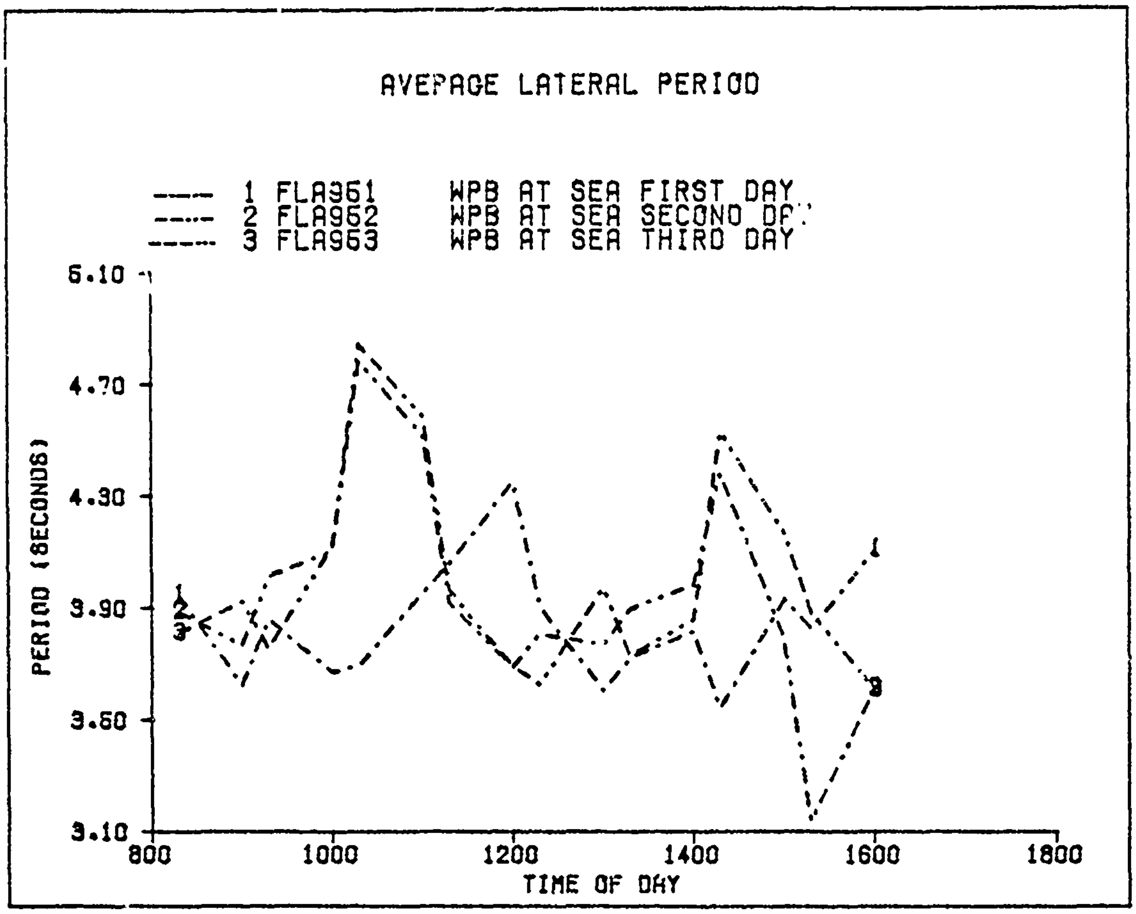

Fig. G-22. Periods of lateral motions aboard the WPB during the three steaming days.

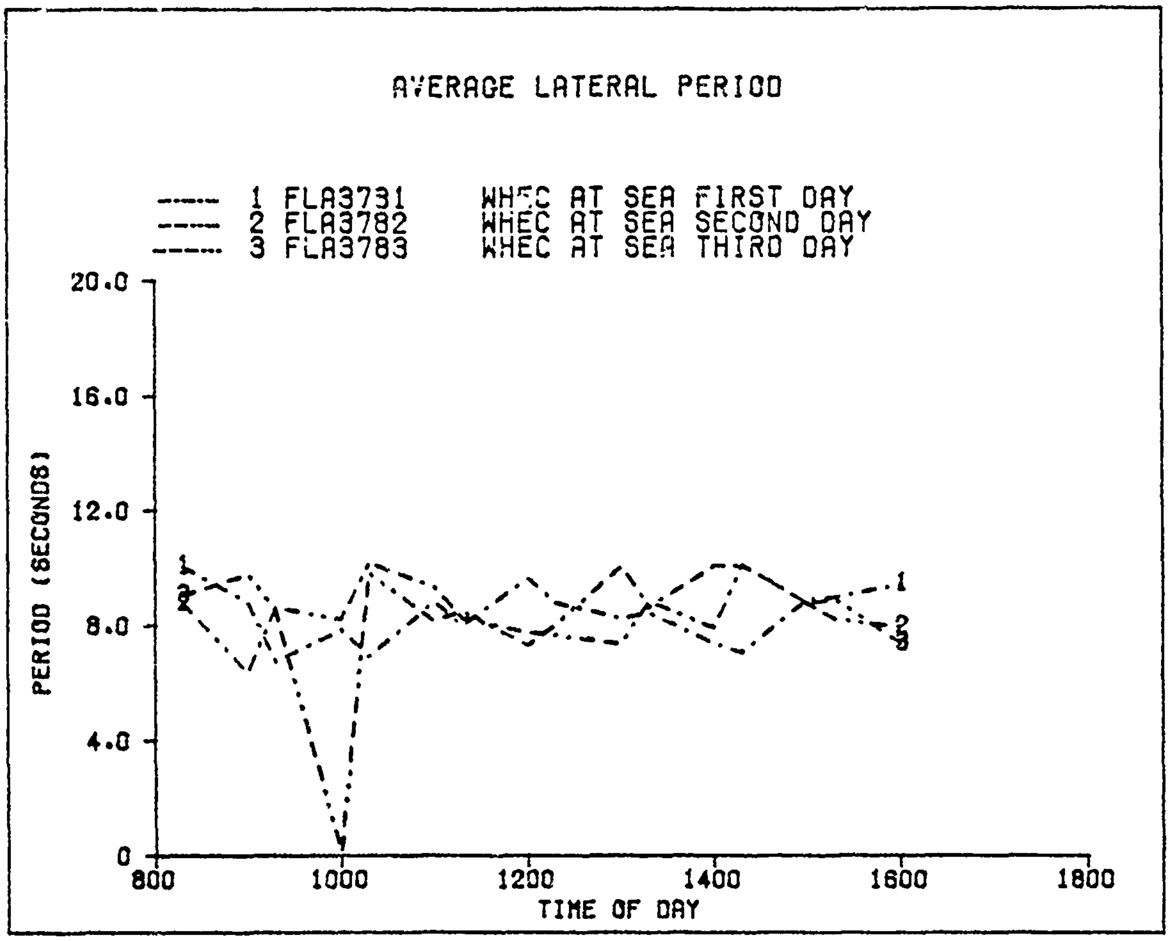

Fig. G-23. Periods of lateral motions aboard the WHEC during the three steaming days.

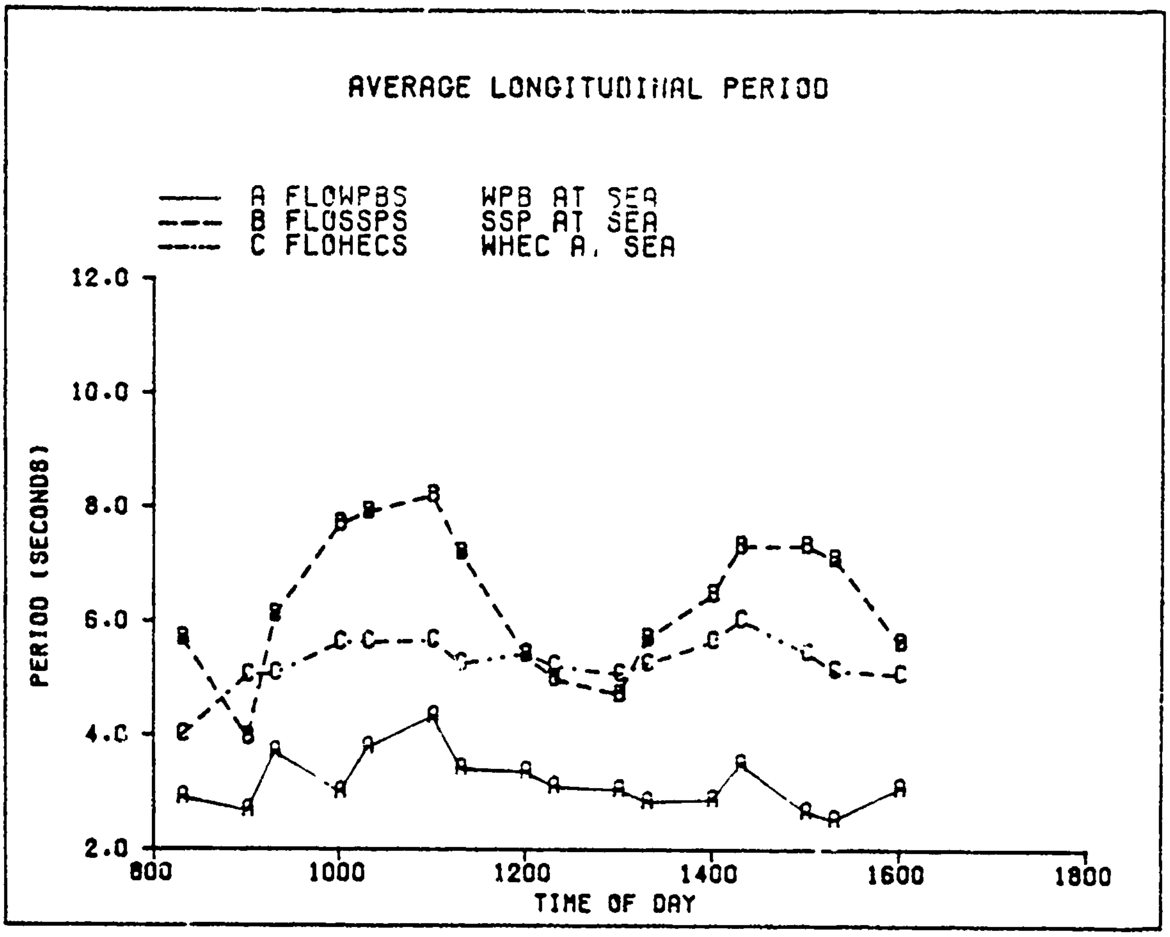

Fig. G-24. Average period of longitudinal motions aboard each vessel during the three steaming days.

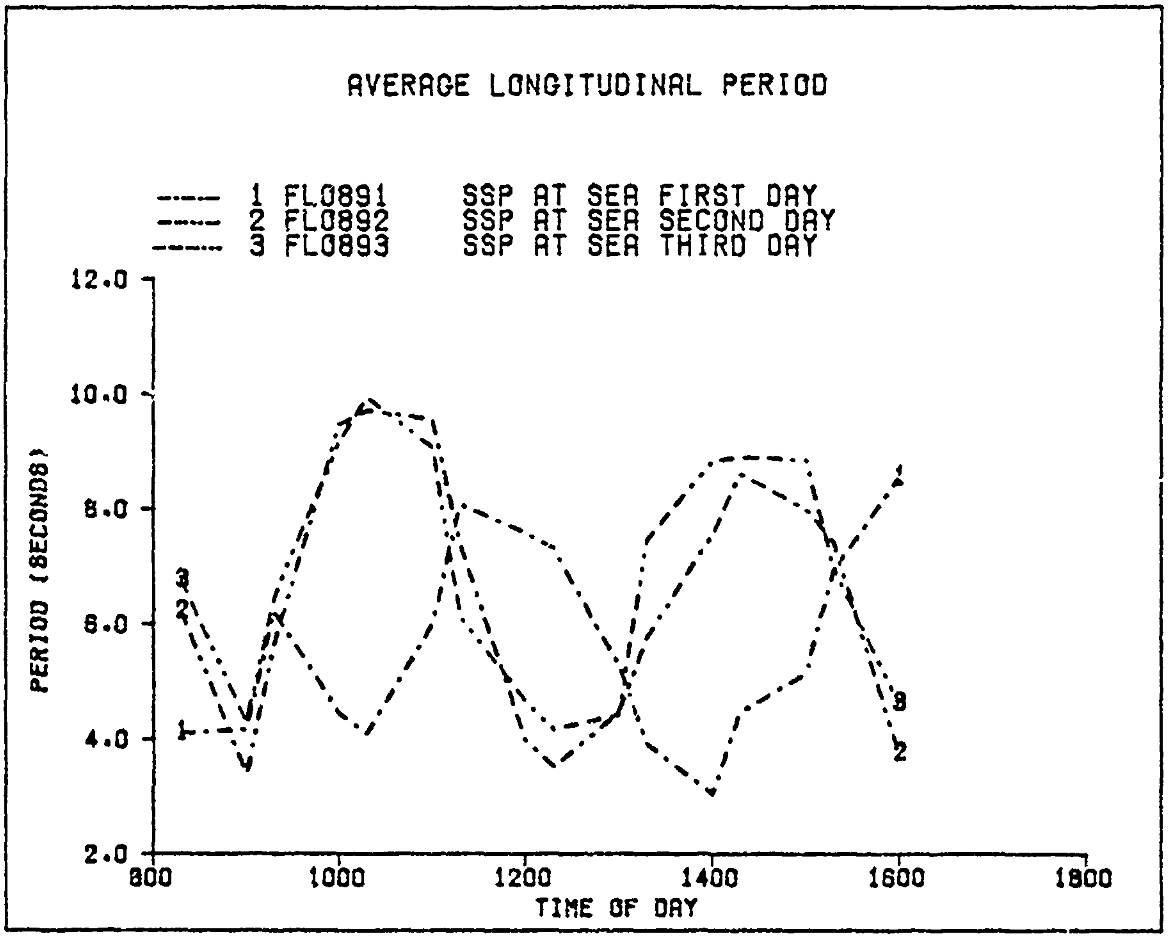

Fig. G-25. Periods of longitudinal motions aboard the SSP during the three steaming days.

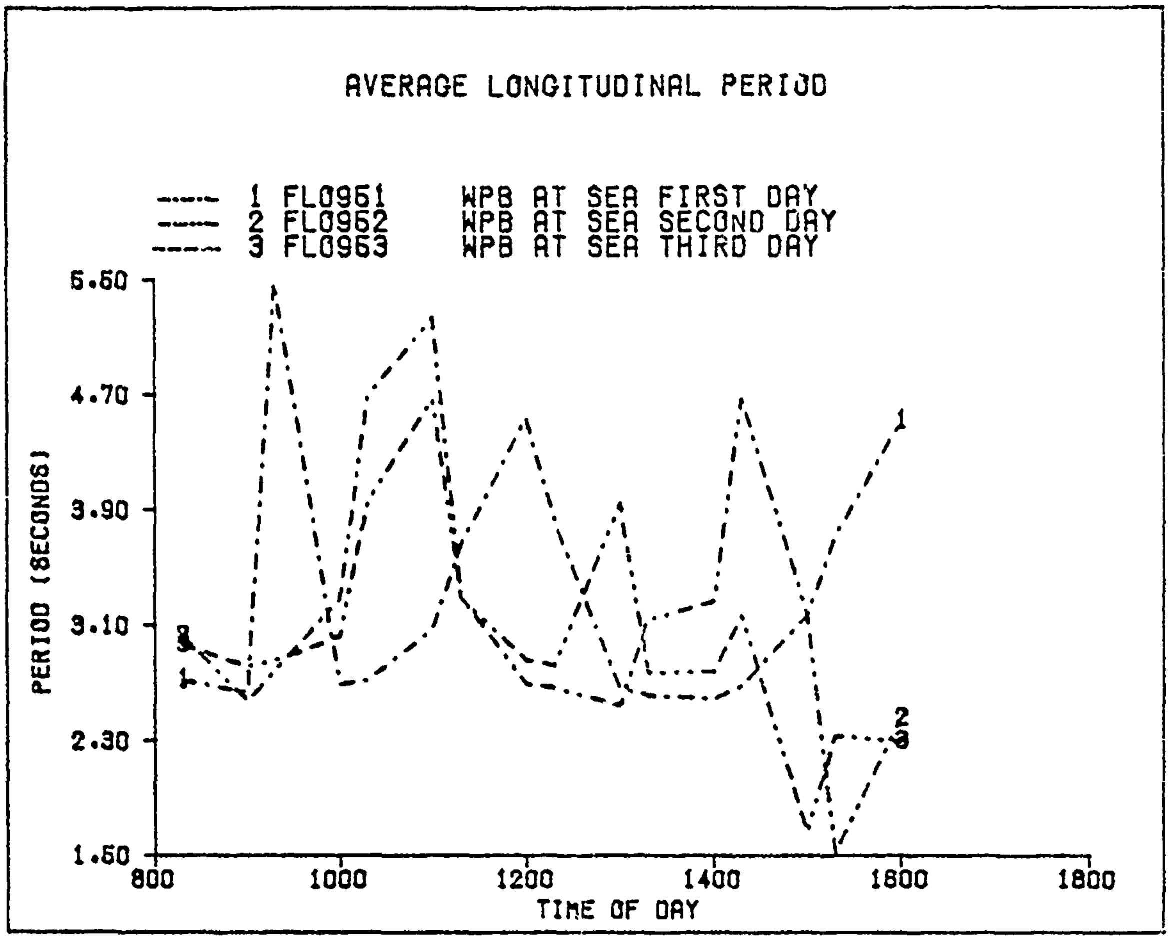

Fig. G-26. Periods of longitudinal motions aboard the WPB during the three steaming days.

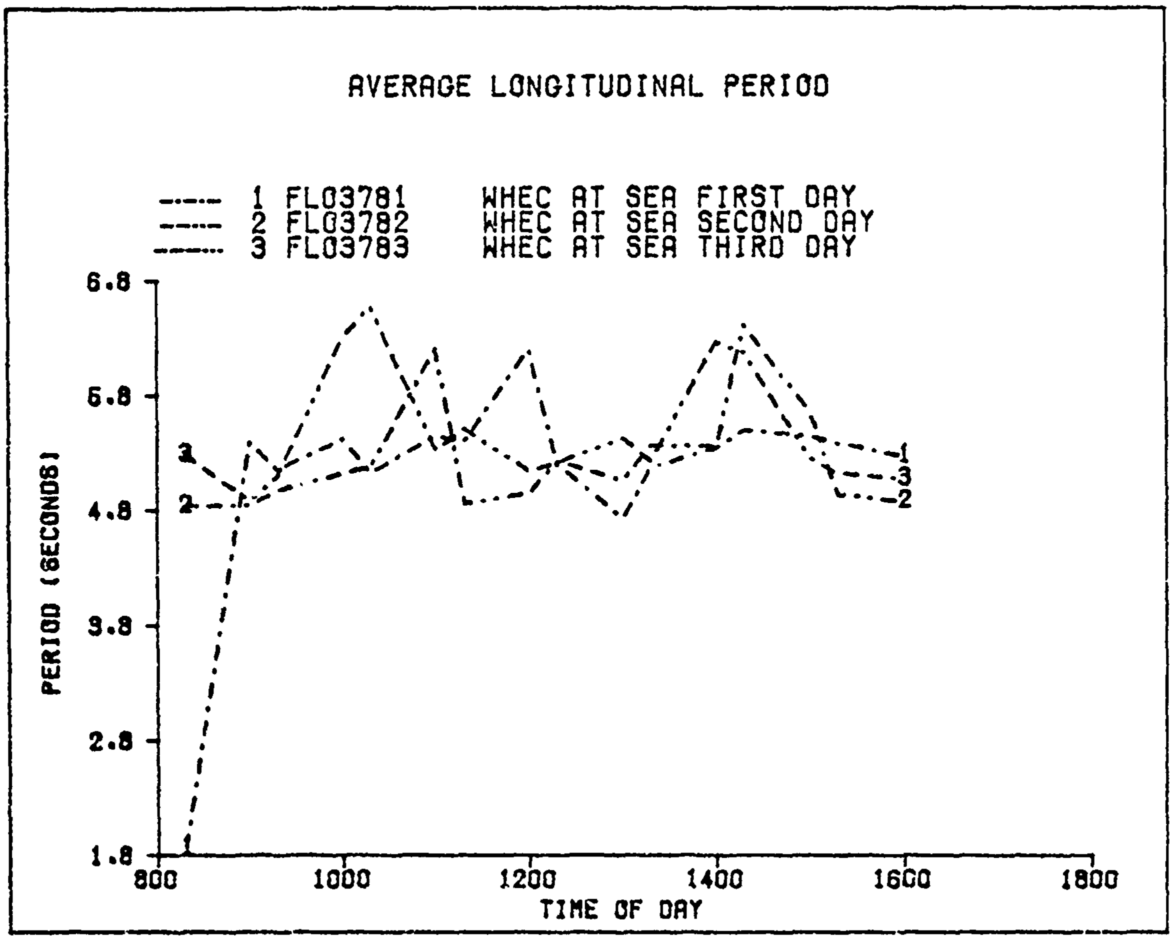

Fig. G-27. Periods of longitudinal motions aboard the WHEC during the three steaming days.

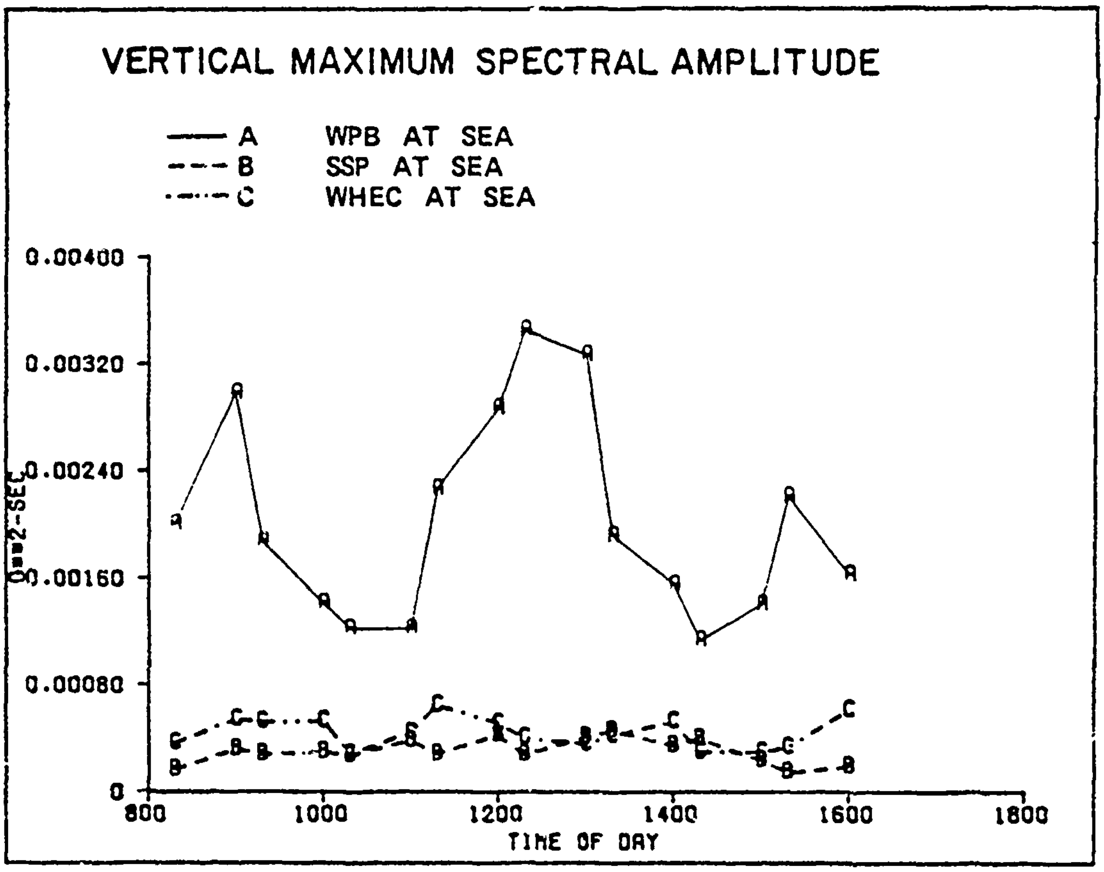

Fig. G-28. Average maximum spectral amplitudes of vertical motions aboard each vessel during the three steaming days.

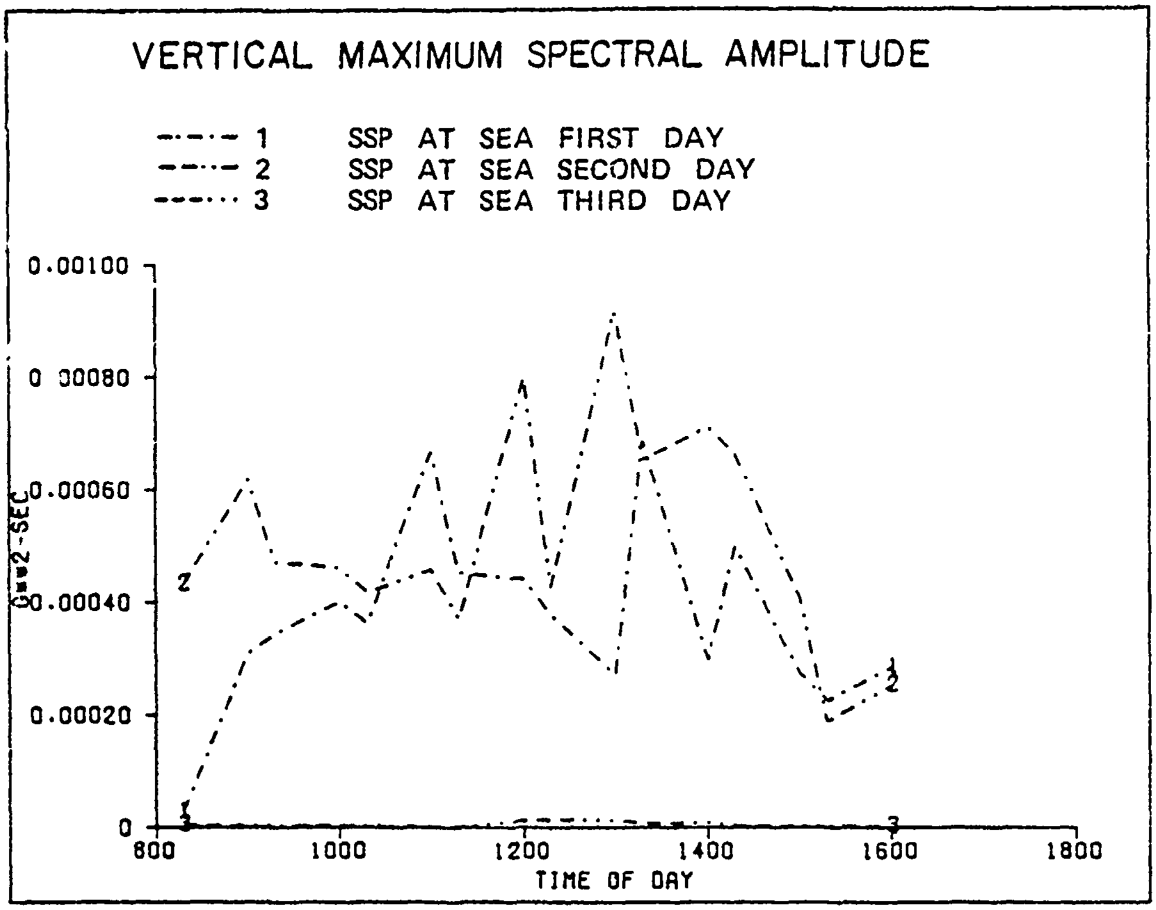

Fig. G-29. Maximum spectral amplitudes of vertical motions aboard the SSP during the three steaming days.

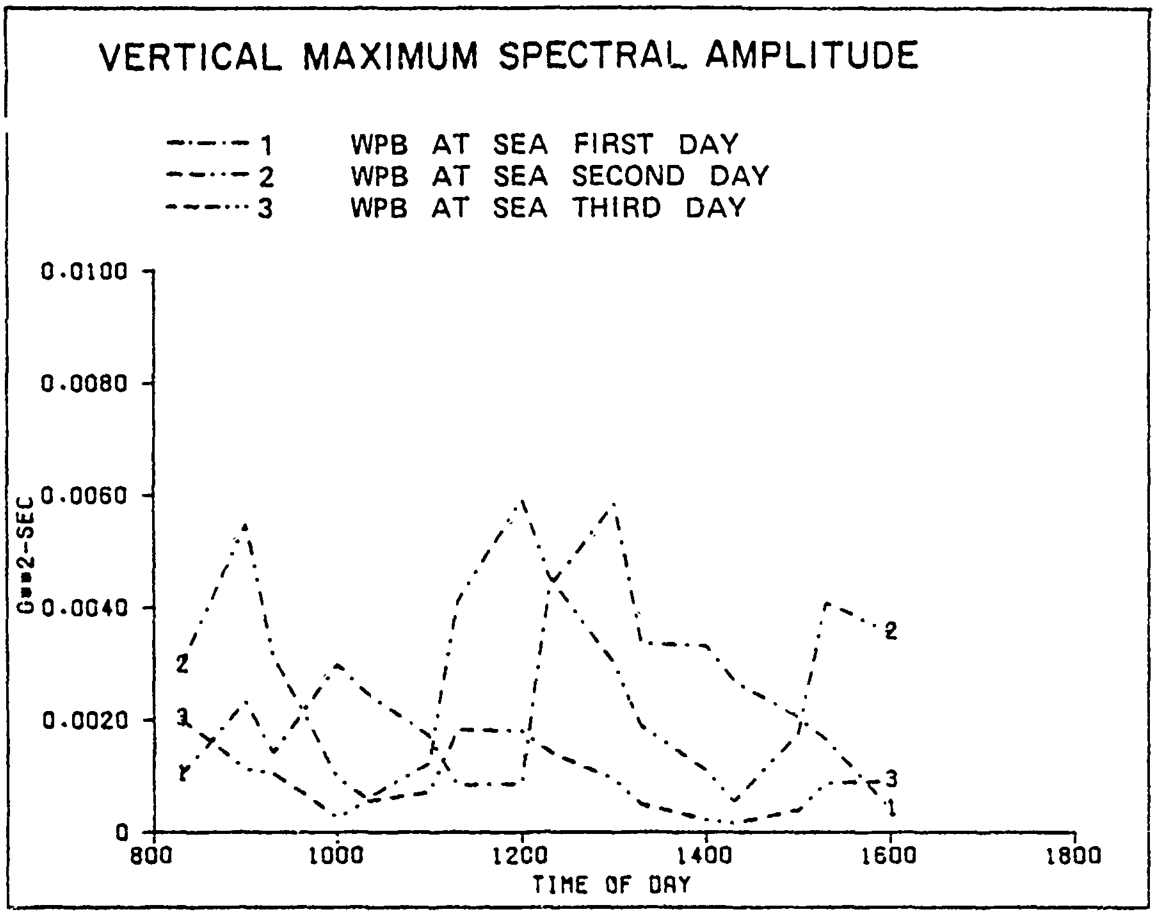

Fig. G-30. Maximum spectral amplitudes of vertical motions aboard the WPB during the three steaming days.

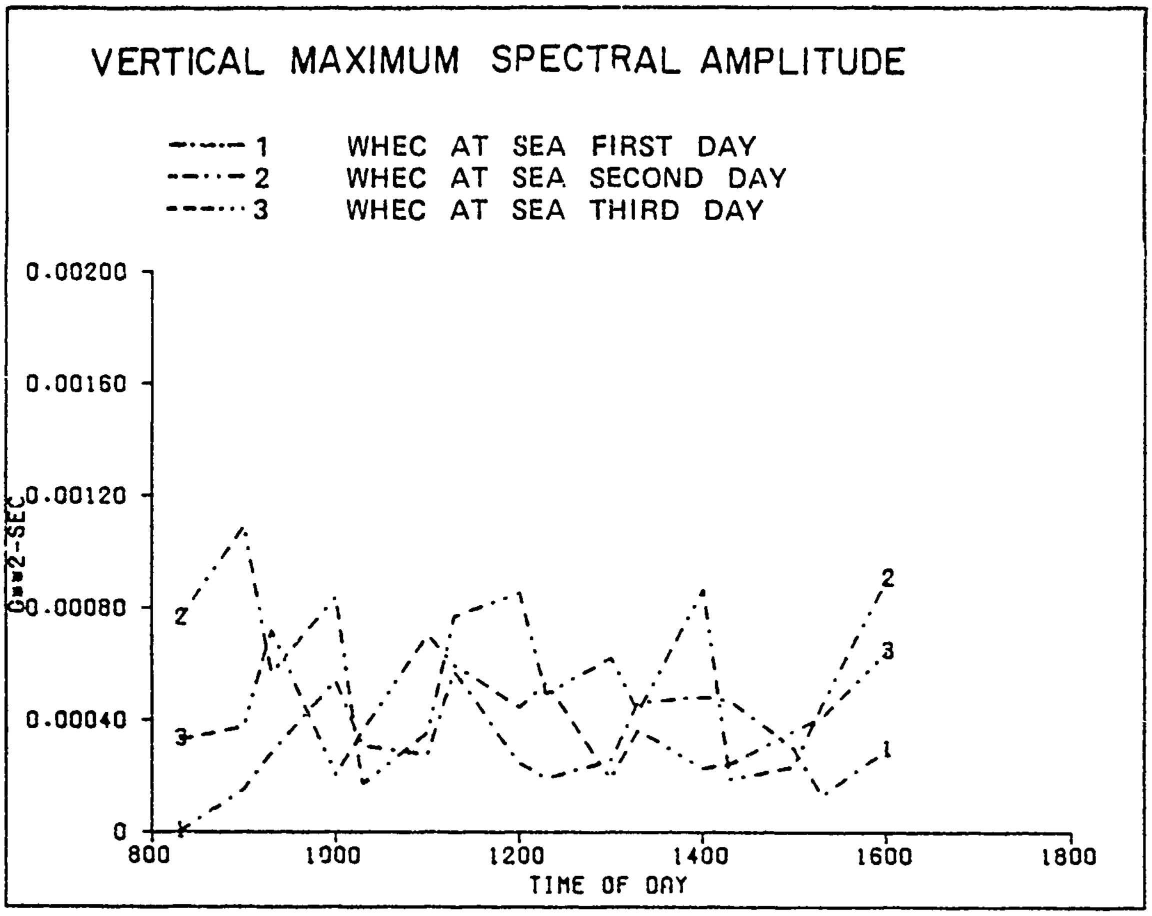

Fig. G-31. Maximum spectral amplitudes of vertical motions aboard the WHEC during the three steaming days.

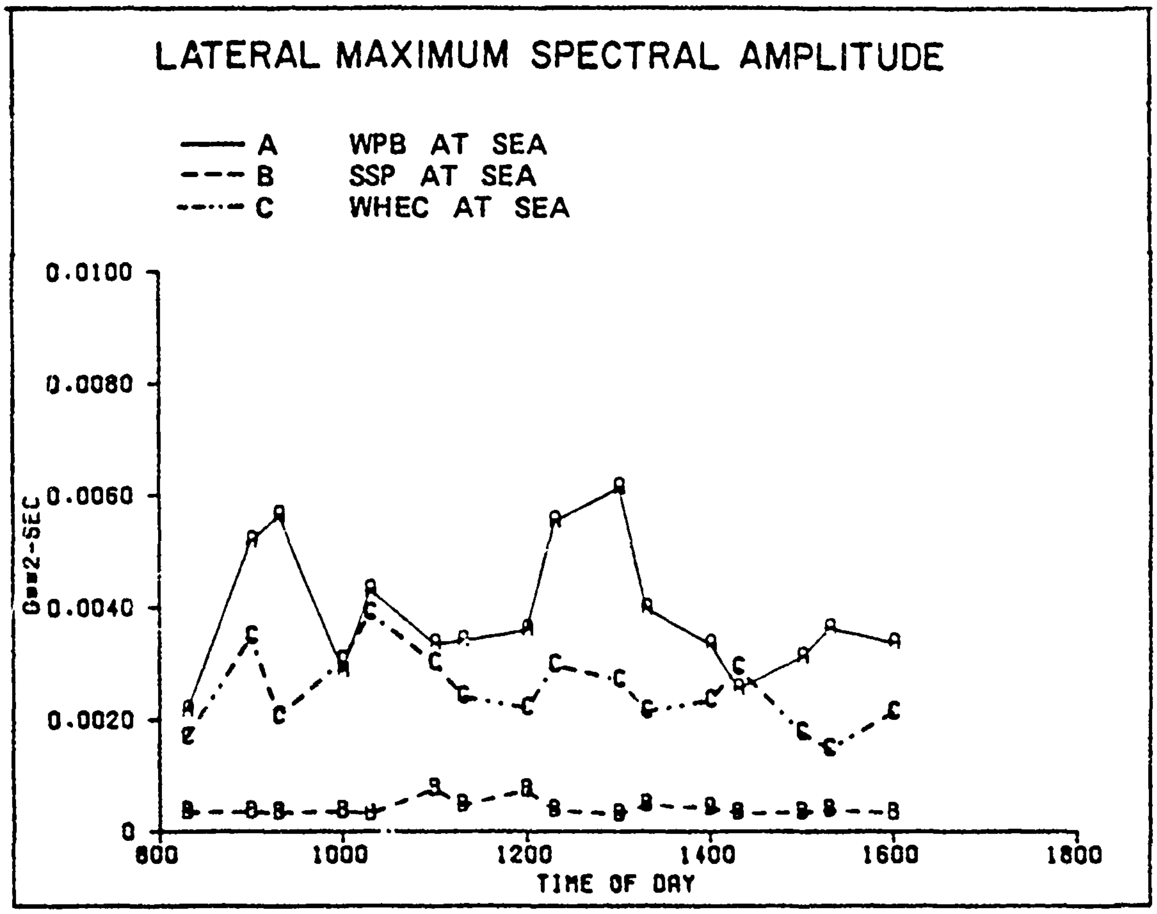

Fig. G-32. Average maximum spectral amplitudes of lateral motions aboard each vessel during the three steaming days.

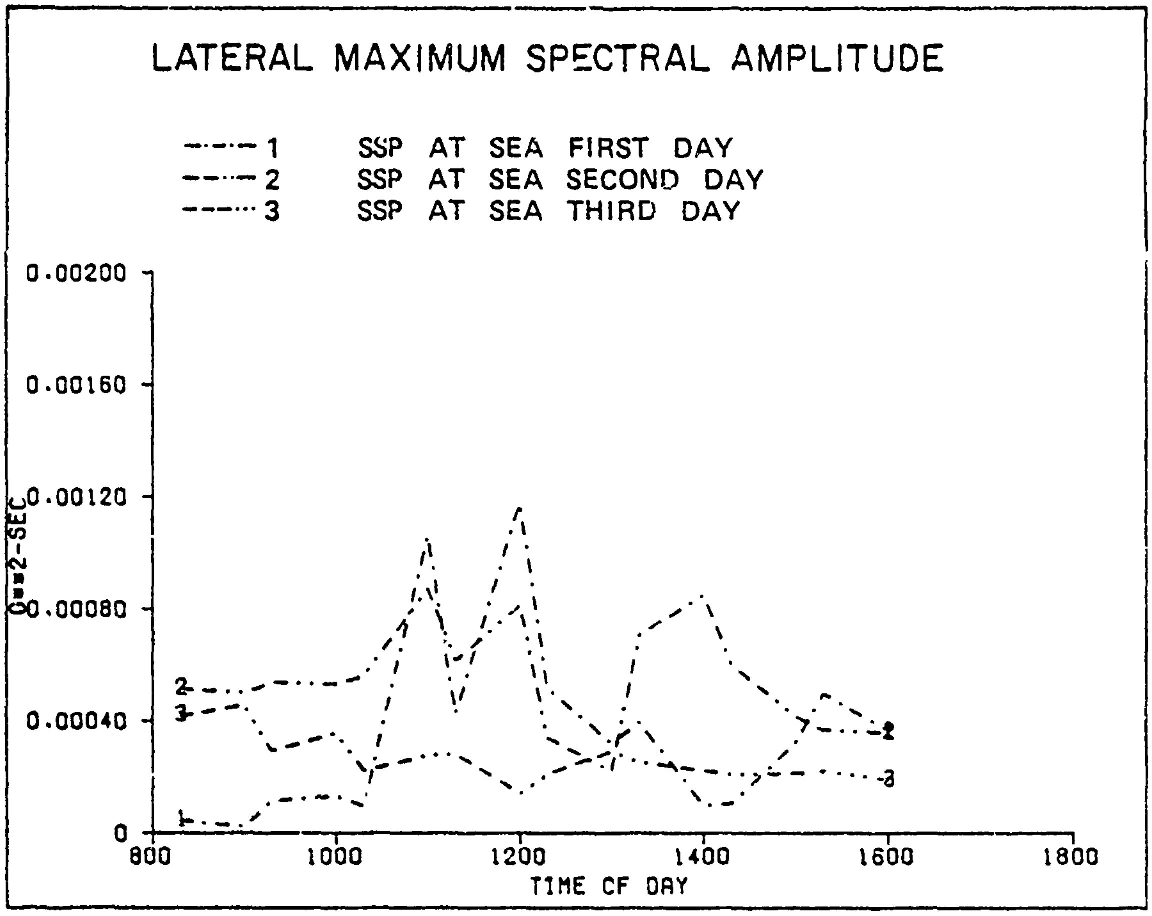

Fig. G-33. Maximum spectral amplitudes of lateral motions aboard the SSP during the three steaming days.

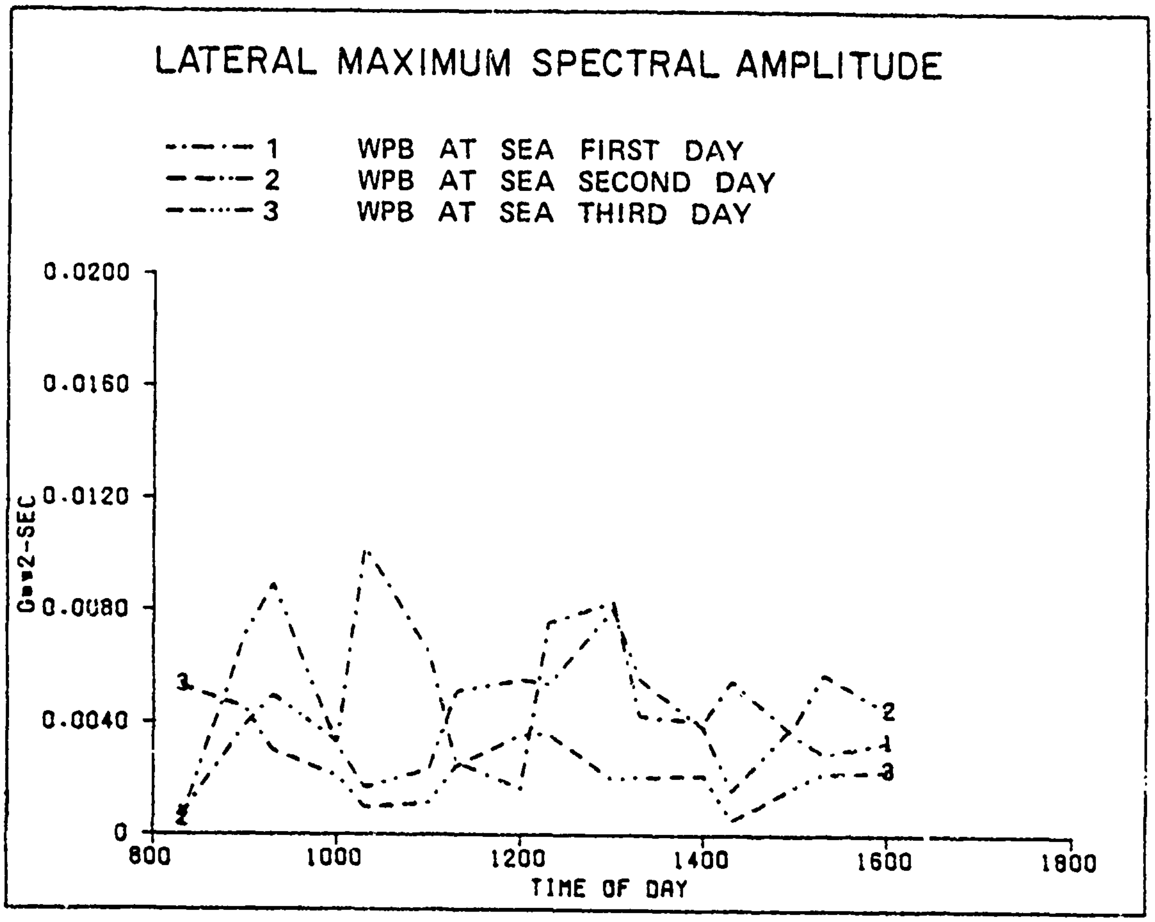

Fig. G-34. Maximum spectral amplitudes of lateral motions aboard the WPB during the three steaming days.

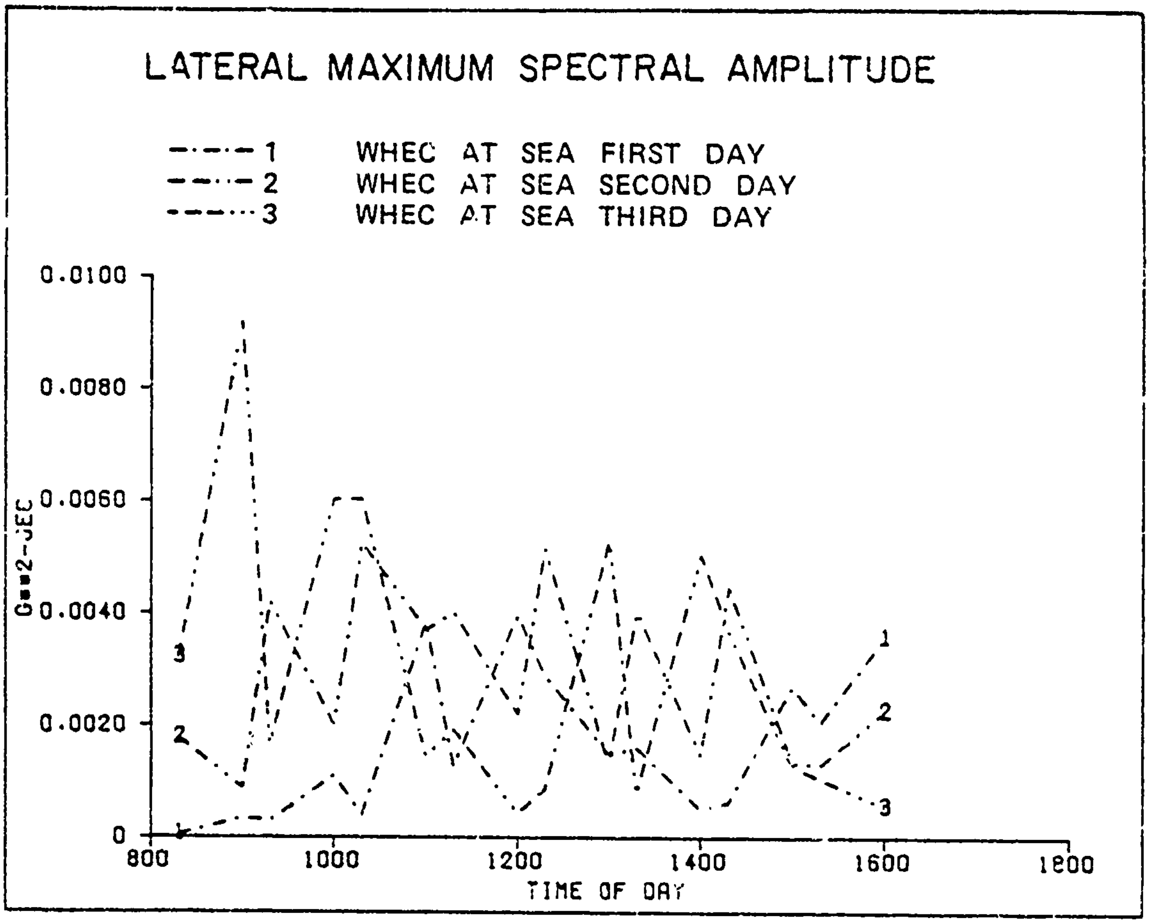

Fig. G-35. Maximum spectral amplitudes of lateral motions aboard the WHEC during the three steaming days.

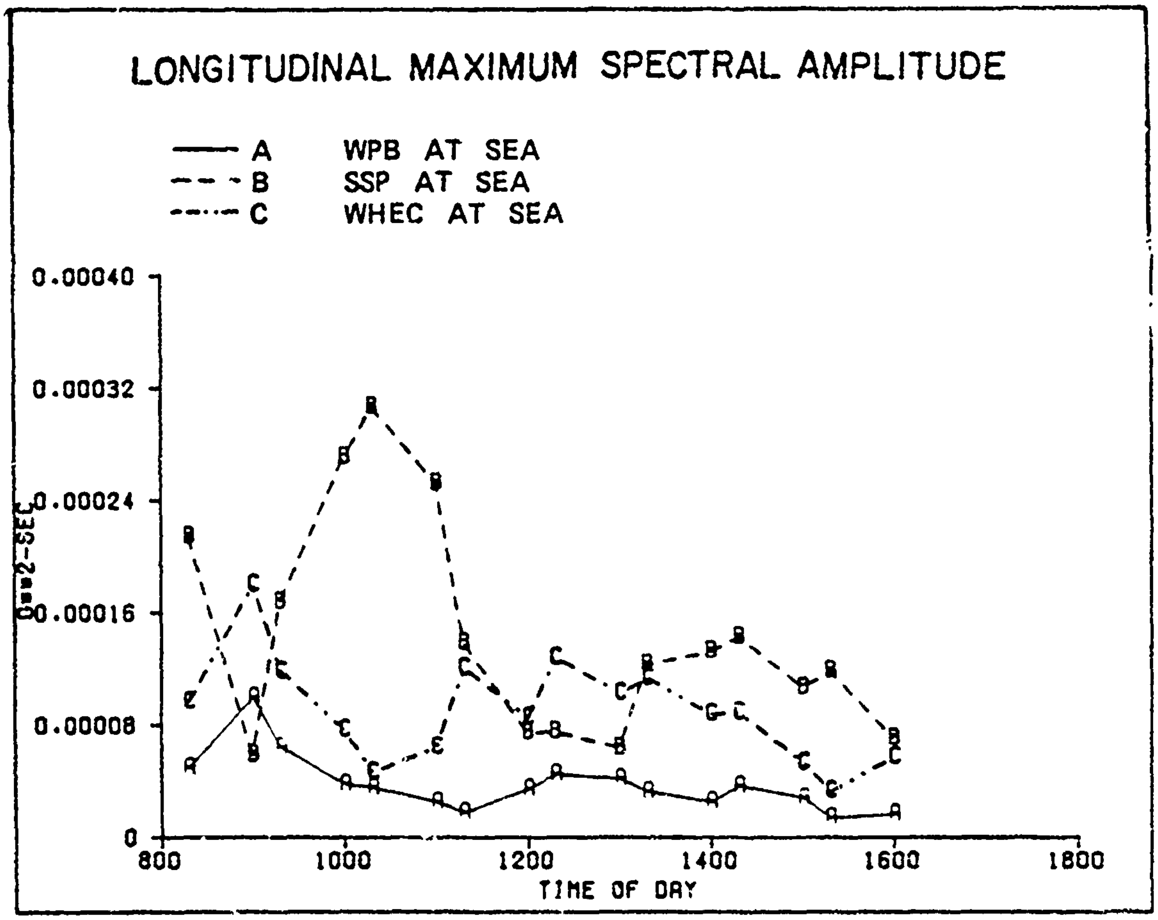

Fig. G-36. Average maximum spectral amplitudes of longitudinal motions aboard each vessel during the three steaming days.

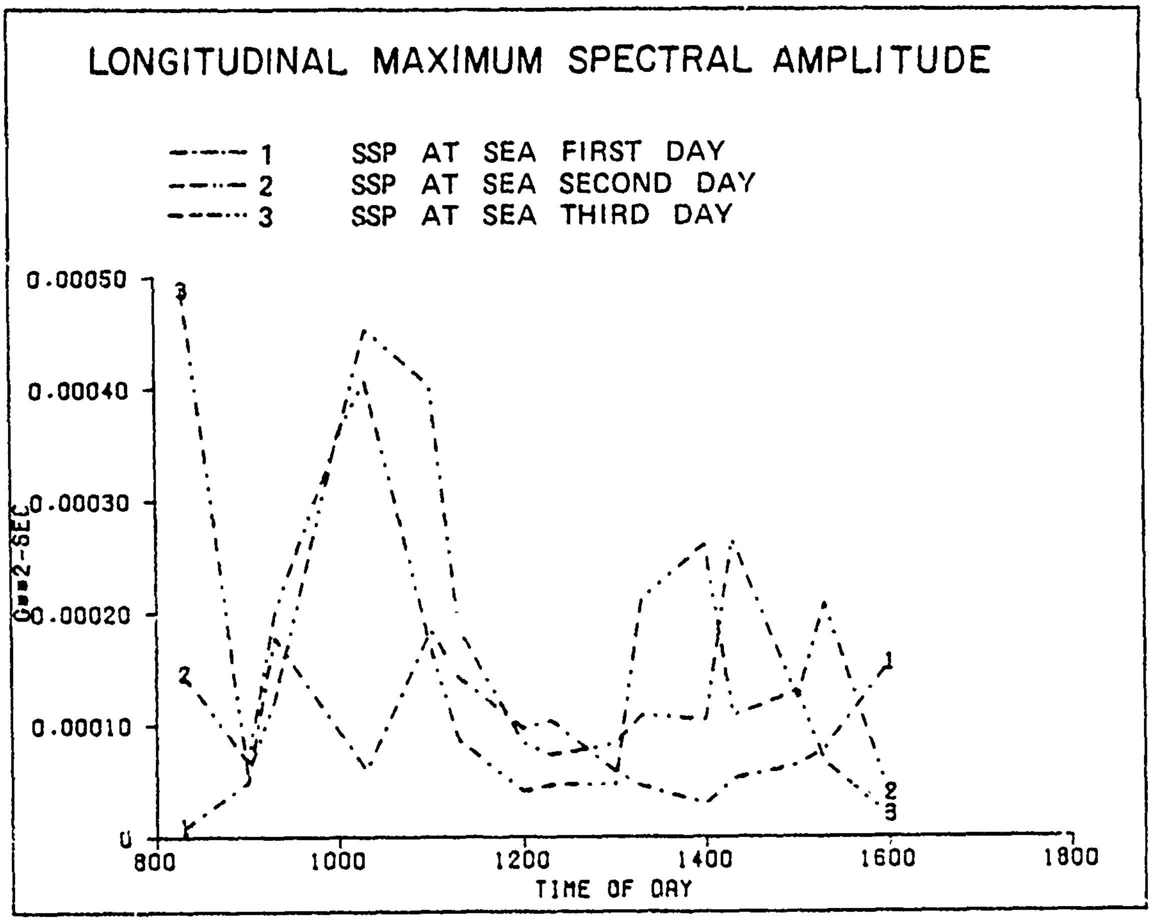

Fig. G-37. Maximum spectral amplitudes of longit inal motions aboard the SSP during the three steaming days.

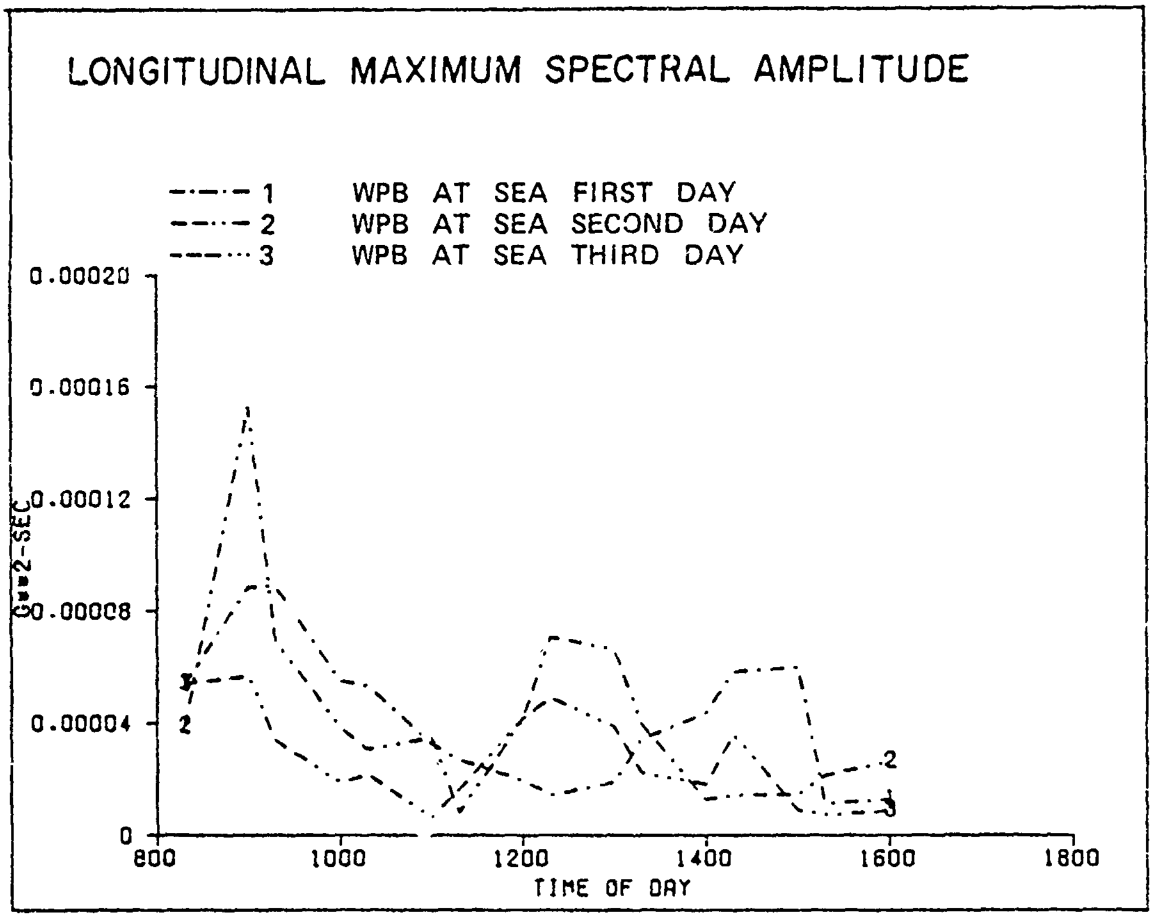

Fig. G-38. Maximum spectral amplitudes of longitudinal motions aboard the WPB during the three steaming days.

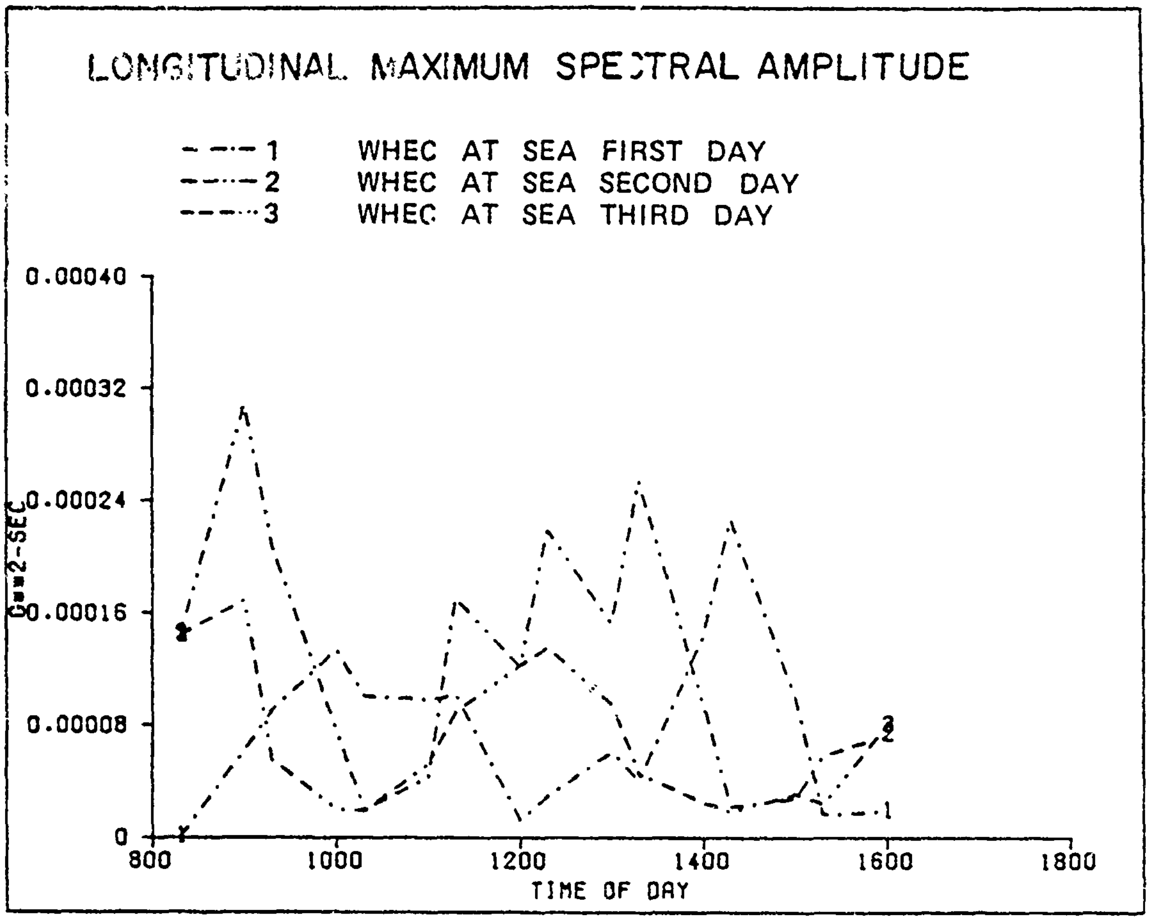

Fig. G-39. Maximum spectral amplitudes of longitudinal motions aboard the WHEC during the three steaming days.

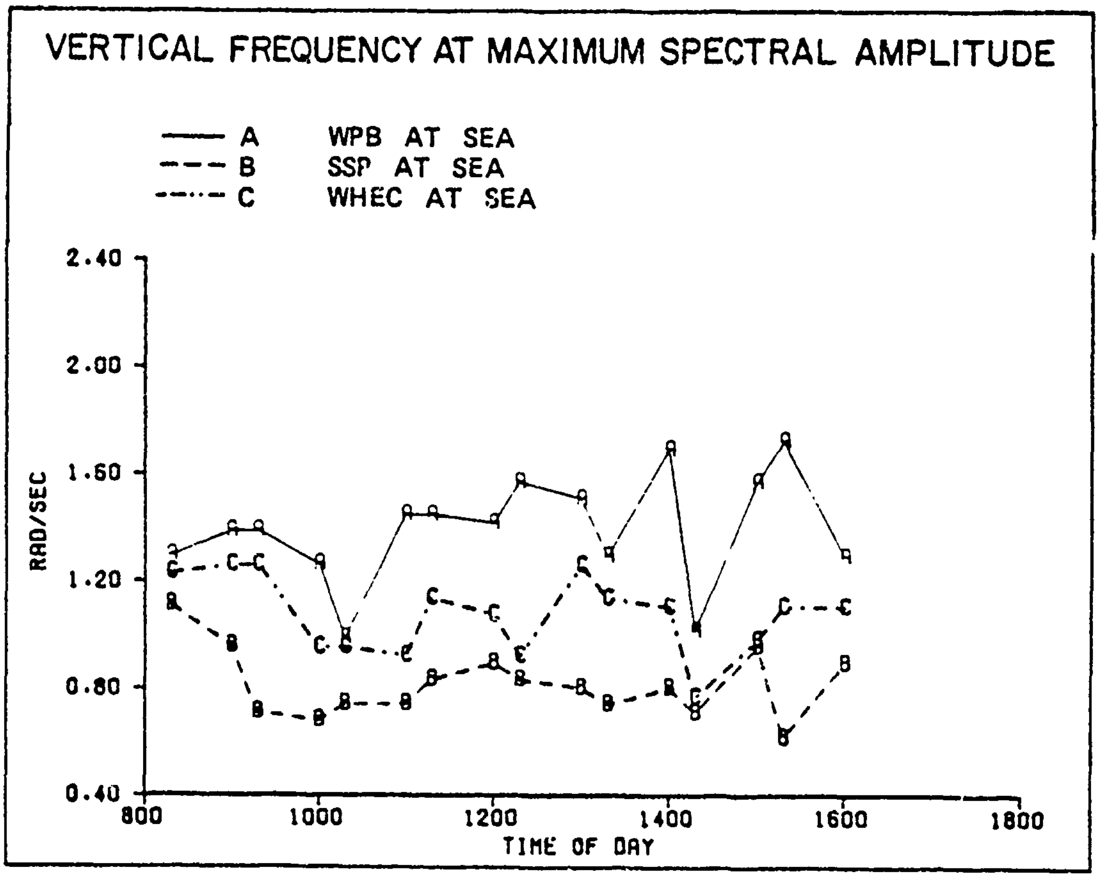

Fig. G-40. Average frequency at maximum spectral amplitudes of vertical motions aboard each vessel during the three steaming days.

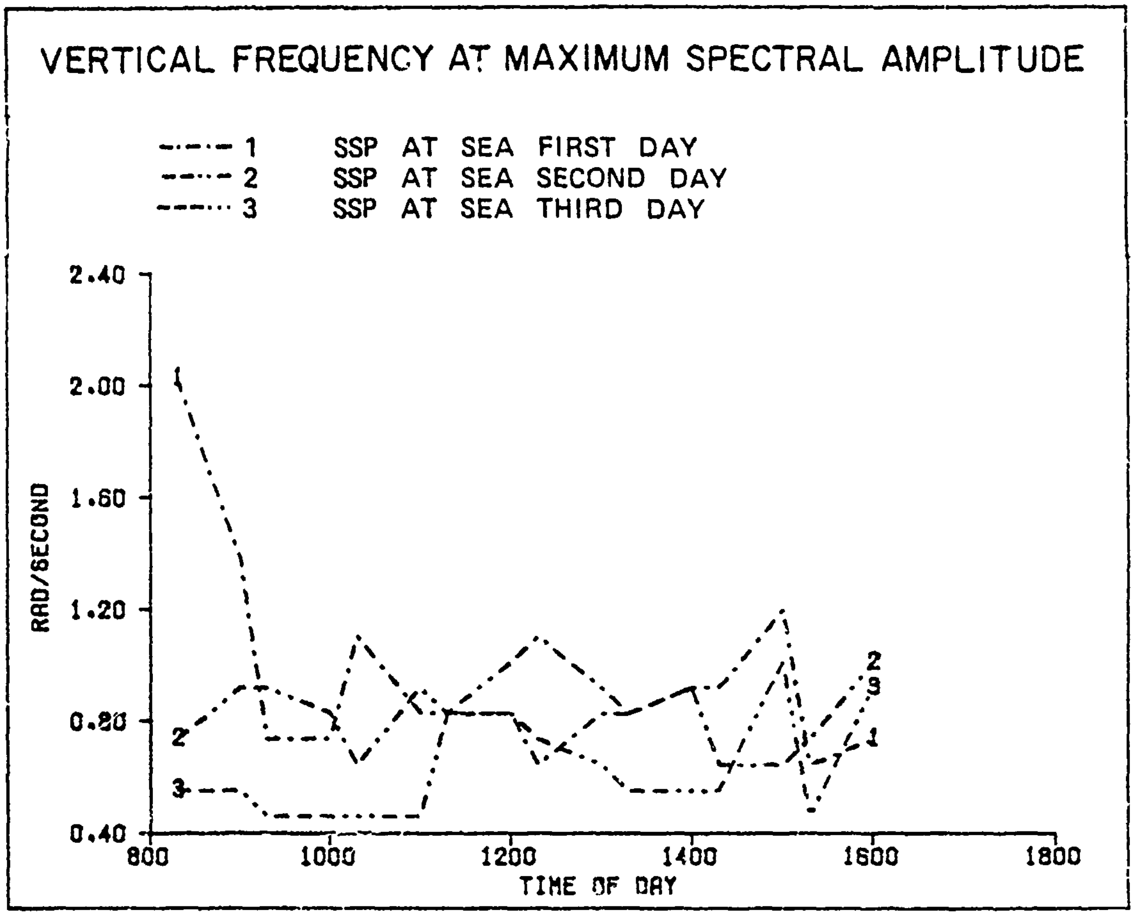

Fig. G-41. Frequency at maximum spectral amplitudes of vertical motions aboard the SSP during the three steaming days.

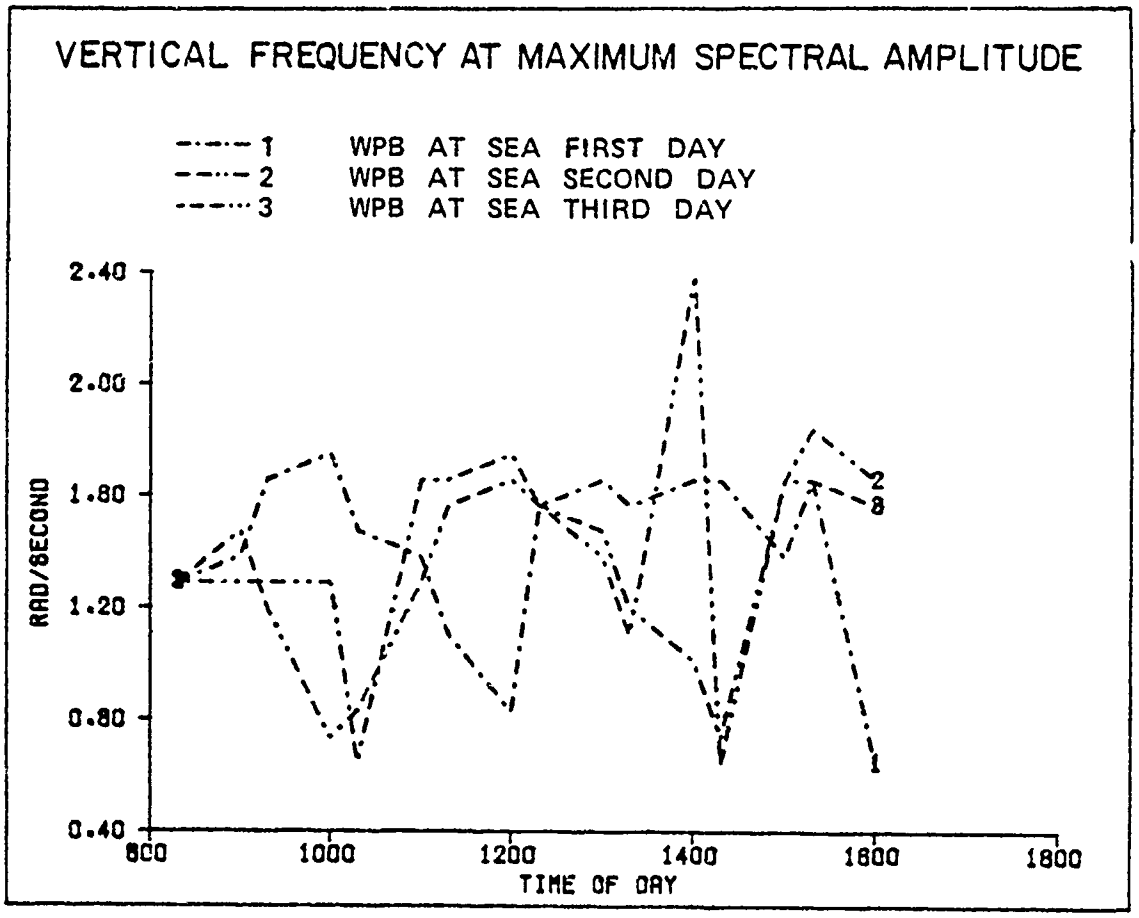

Fig. G-42. Frequency at maximum spectral amplitudes of vertical motions aboard the WPB during the three steaming days.

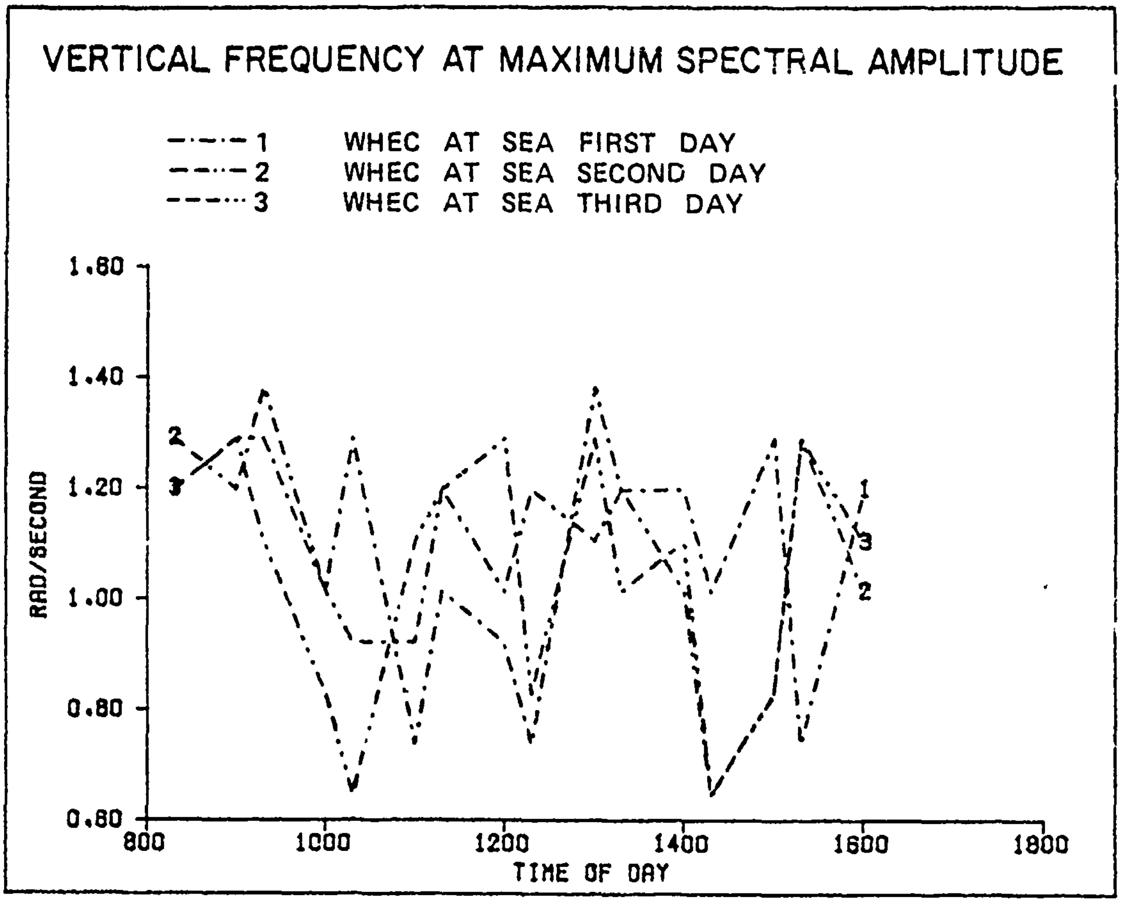

Fig. G-43. Frequency at maximum spectral amplitudes of vertical motions aboard the WHEC during the three steaming days.

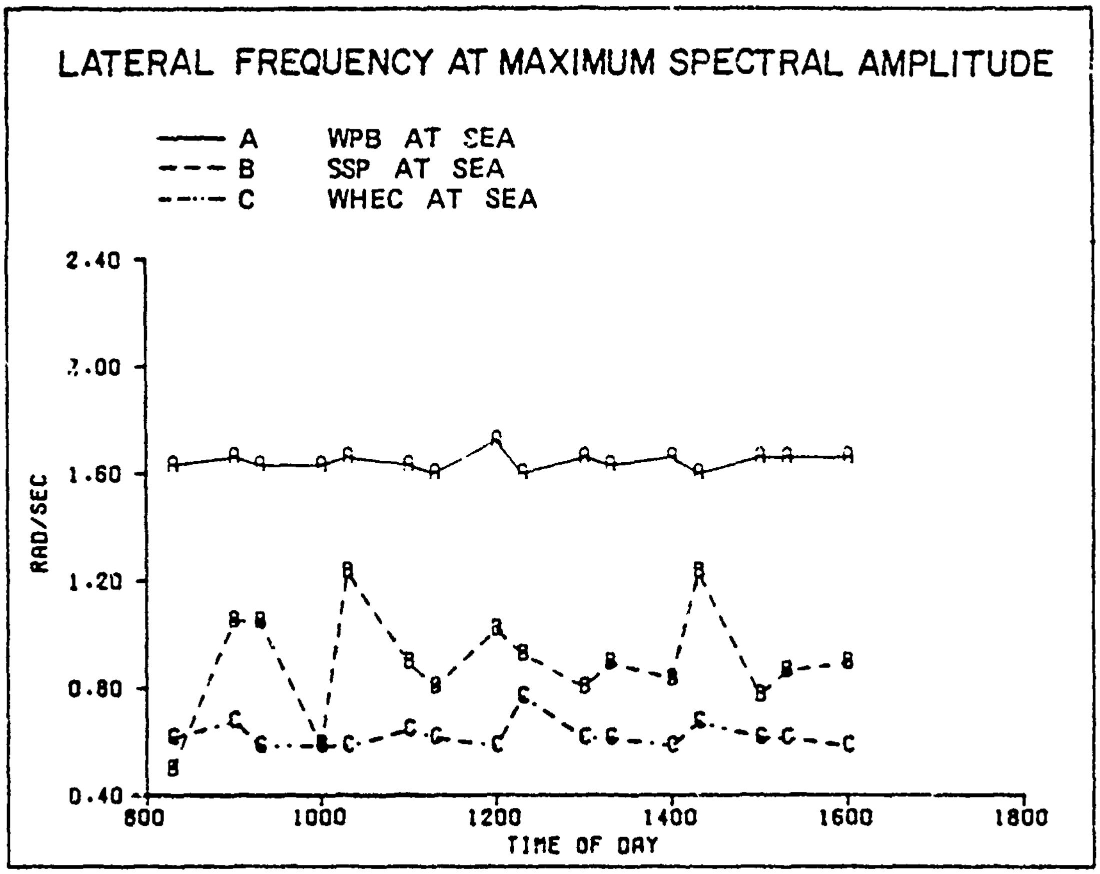

Fig. G-44. Average frequency at maximum spectral amplitudes of lateral motions aboard each vessel during the three steaming days.

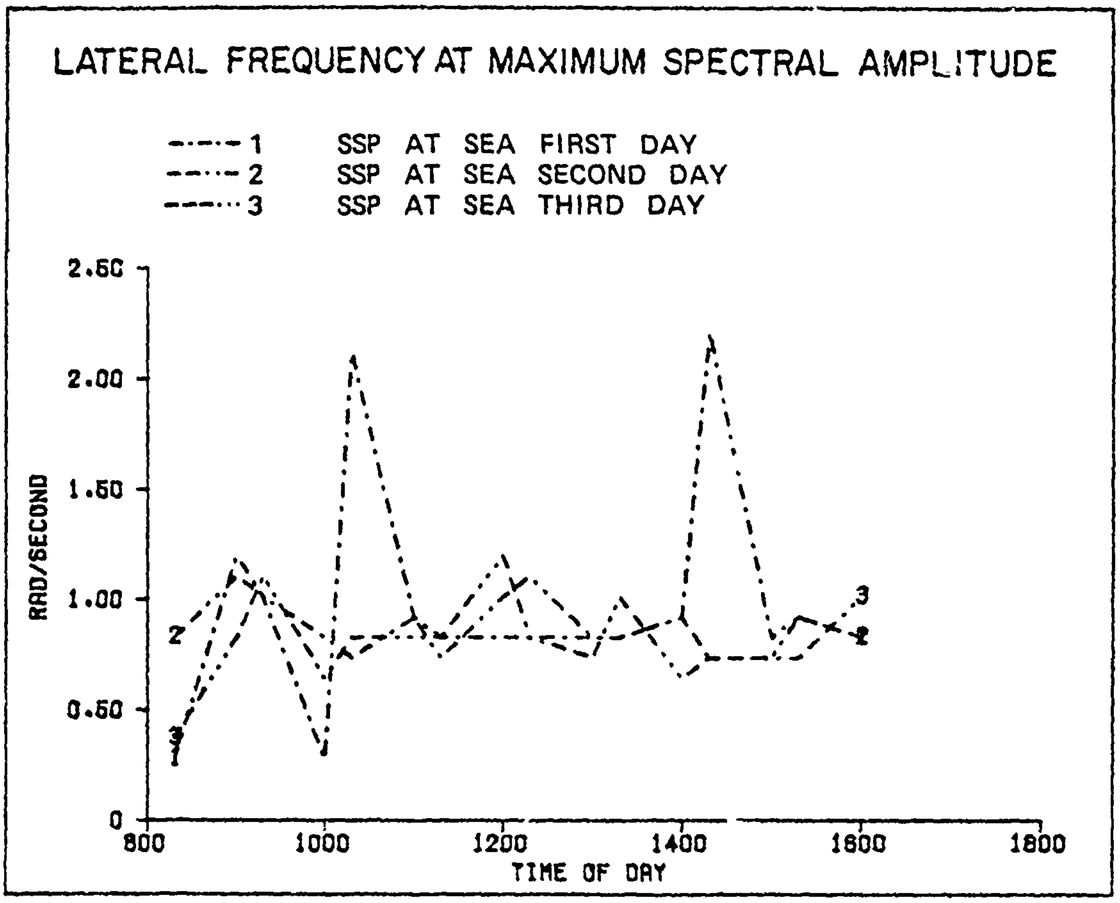

Fig. G-45. Frequencies at maximum spectral amplitudes of lateral motions aboard the SSP during the three steaming days.

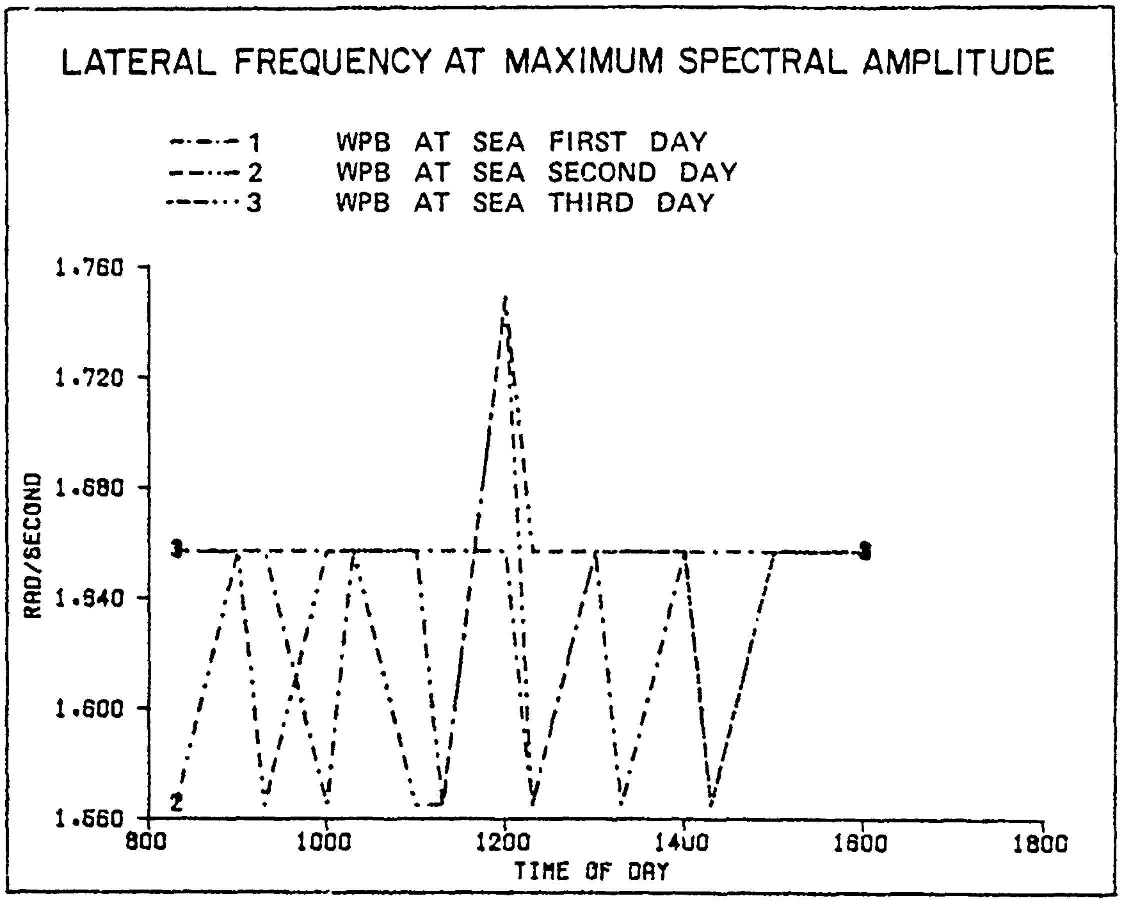

Fig. G-46. Frequencies at maximum spectral amplitudes of lateral motions aboard the WPB during the three steaming days.

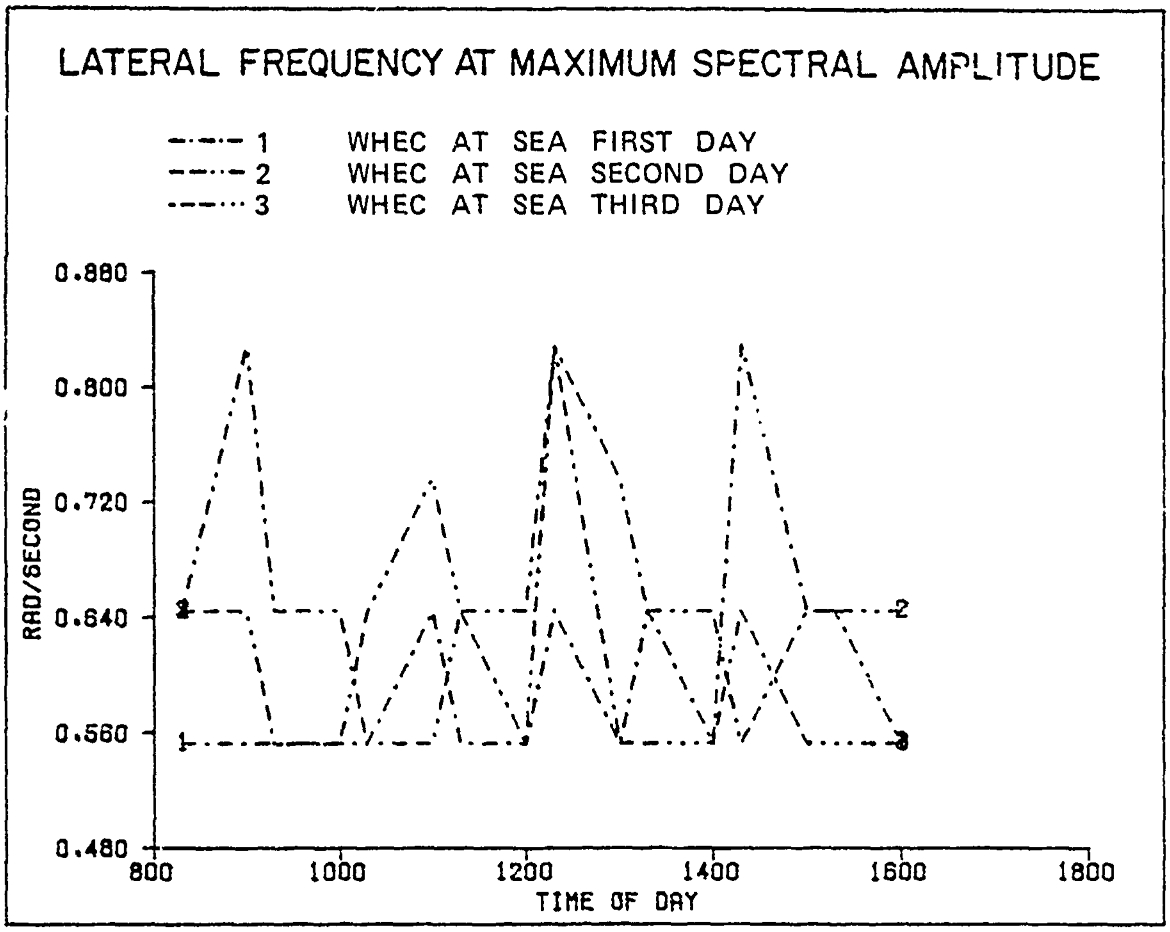

Fig. G-47. Frequencies at maximum spectral amp' ‘ ˍdes of lateral motions aboard the WHEC dur_ ːg the three steaming days.

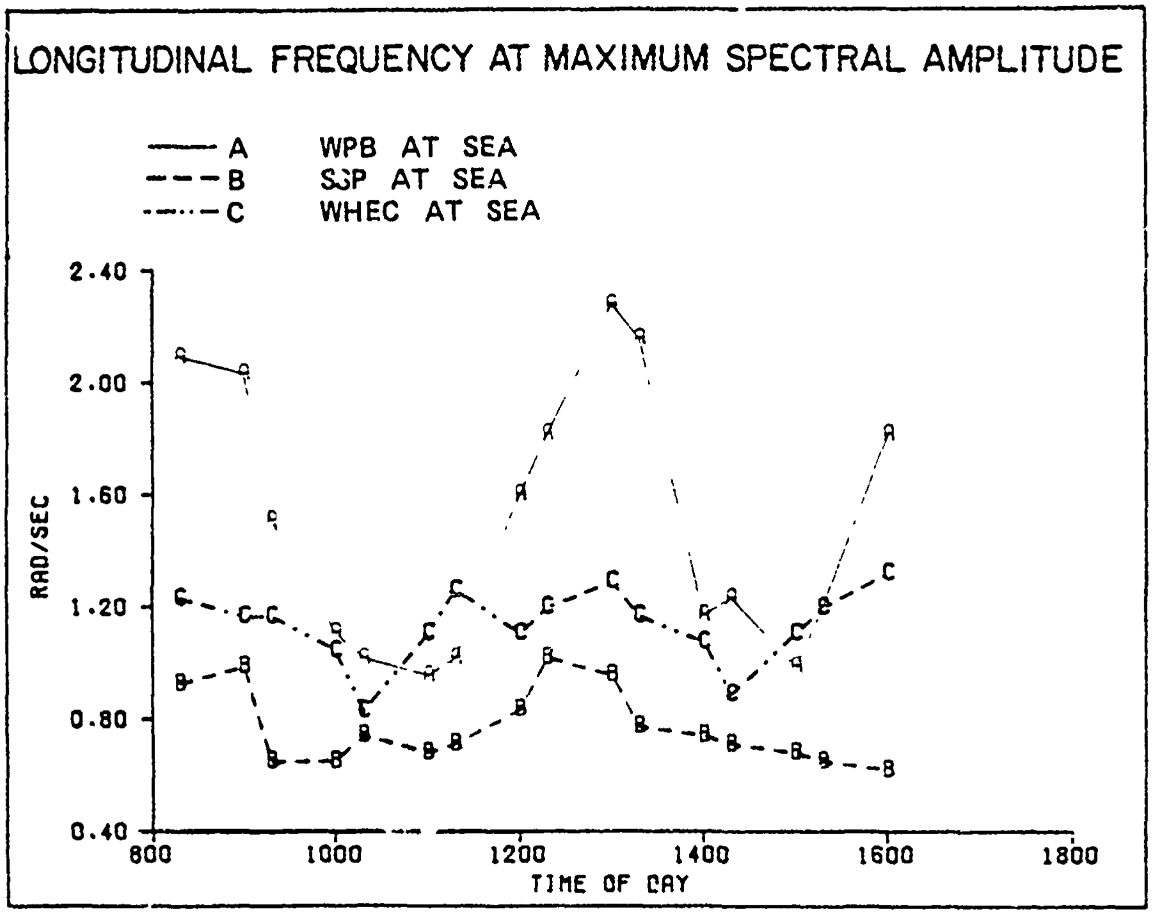

Fig. G-48. Average frequency at maximum spectral amplitudes of longitudinal motions aboard each vessel during the three steaming days.

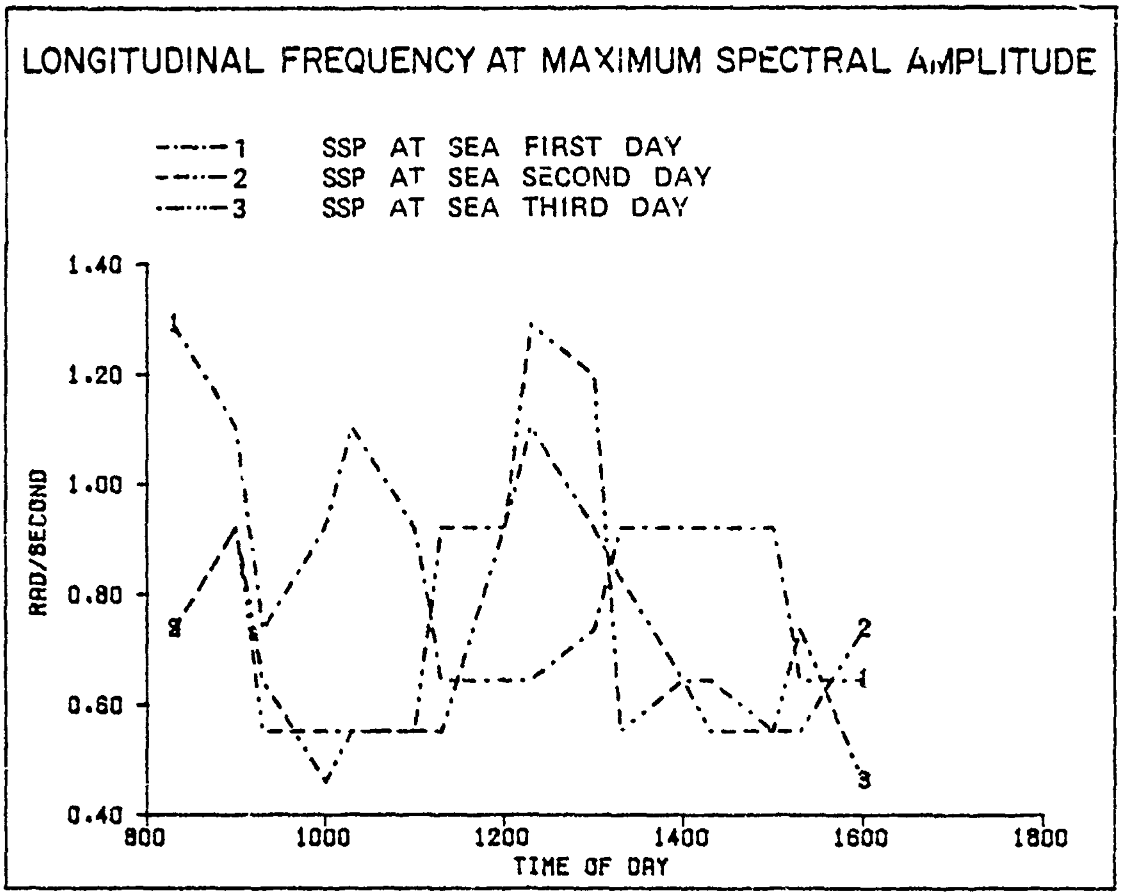

Fig. G-49. Frequency at maximum spectral amplitudes of longitudinal motions aboard the SSP during the three steaming days.

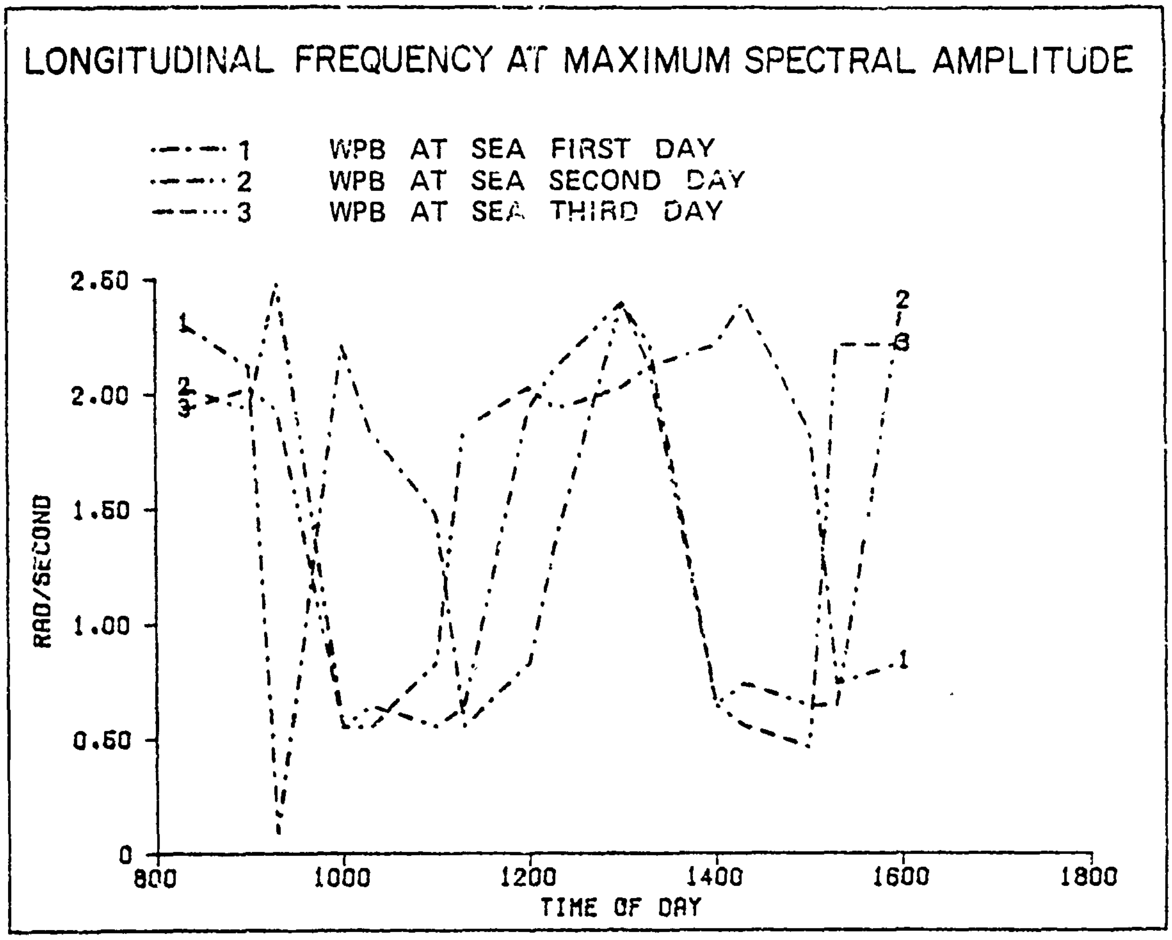

Fig. G-50. Frequency at maximum spectral amplitudes of longitudinal motions aboard the WPB during the three steaming days.

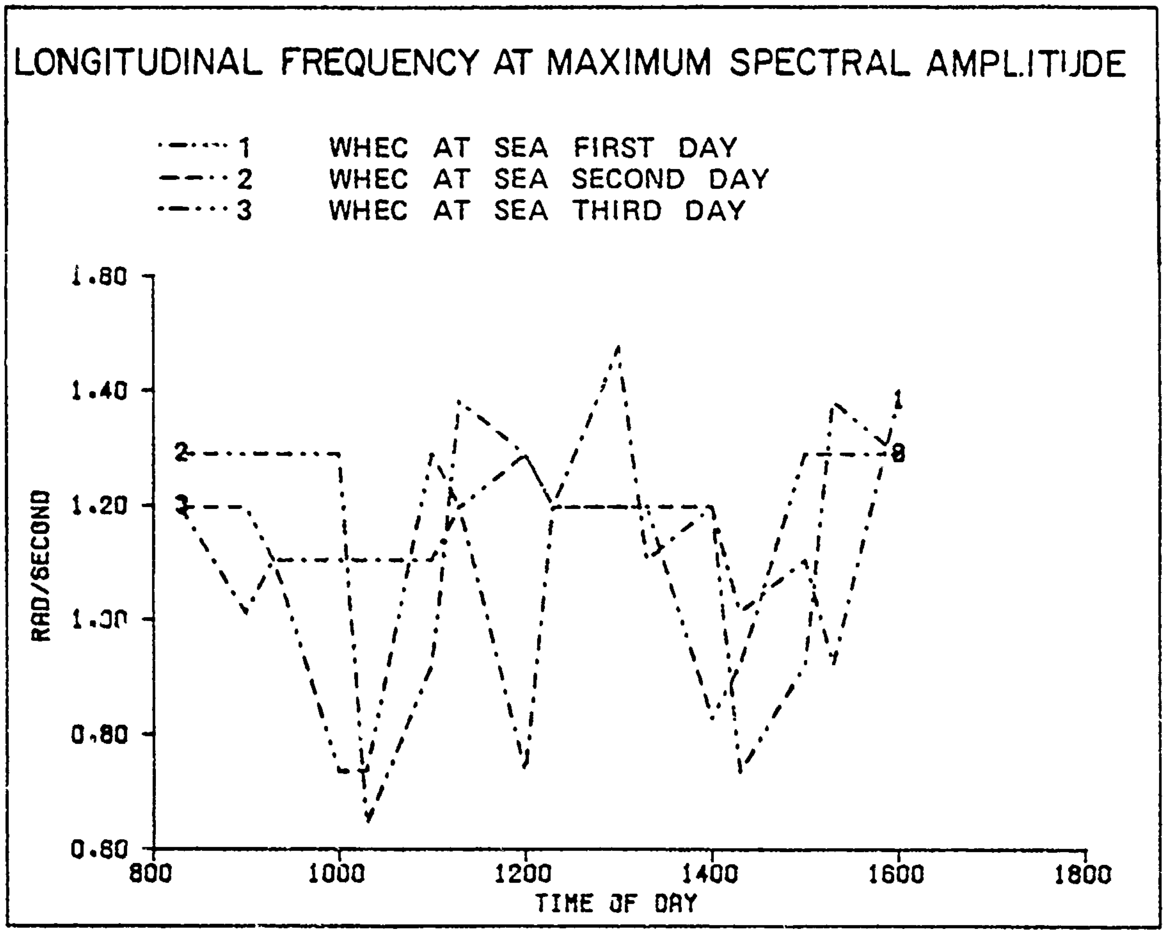

Fig. G-51. Frequency at maximum spectral amplitudes of longitudinal motions aboard the WHEC during the three steaming days.

APPENDIX H

APPENDIX H

DEFINITIONS OF SEA STATE CONDITIONS: WAVE AND SEA FOR FULLY ARISEN SEA

Sea — General		Wind				Sea								
Sea State	Description	(Beaufort) Wind force	Description	Range (knots)	Wind Velocity (knots)	Wave Height: Average	Wave Height: Significant	Wave Height: Average of One-Tenth Highest	Significant Range Periods (sec)	Periods of maximum Energy of Spectra $T_{max} = T_c$	Average Period $\bar{T}_c$	Average Wave-length $\bar{L}_w$ (ft unless otherwise indicated)	Minimum Fetch (nautical miles)	Minimum Duration (hr unless otherwise indicated)
	Sea like a mirror	0	Calm	1	0	0	0	0	—	—	—	—	—	—
0	Ripples with the appearance of scales are formed, but without foam crests.	1	Light airs	1–3	2	0.04	0.01	0.09	1.2	0.75	0.5	10 in	5	18 min
1	Small wavelets, short but pronounced crests have a glossy appearance, but do not break.	2	Light breeze	4–6	5	0.3	0.5	0.6	0.4–2.8	1.9	1.3	6.7 ft	8	39 min
	Large wavelets, crests begin to break. Foam of glossy appearance. Perhaps scattered with horses.	3	Gentle breeze	7–10	8.5	0.8	1.3	1.5	0.8–5.0	3.2	2.3	20	9.8	1.7
					10	1.1	1.8	2.3	1.0–6.0	3.2	2.7	27	10	2.4
2					12	1.6	2.6	3.3	1.0–7.0	4.5	3.2	40	18	3.8
	Small waves, becoming larger; fairly frequent white horses.	4	Moderate breeze	11–16	13.5	2.1	3.3	4.2	1.4–7.6	5.1	3.6	52	24	4.8
					14	2.3	3.6	4.6	1.5–7.8	5.3	3.8	59	28	5.2
3					16	2.9	4.7	6.0	2.0–8.8	6.0	4.3	71	40	6.6
					18	3.7	5.9	7.5	2.5–10.0	6.8	4.8	90	55	8.3
4	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).	5	Fresh breeze	17–21	19	4.1	6.6	8.4	2.8–10.6	7.2	5.1	99	65	9.2
					20	4.6	7.3	9.3	3.0–11.1	7.5	5.4	111	75	10
5					22	5.5	8.8	11.2	3.4–12.2	8.3	5.9	134	100	12
	Large waves begin to form, white crests are more extensive everywhere (probably some spray).	6	Strong breeze	22–27	24	6.6	10.5	13.3	3.7–13.5	9.0	6.4	160	130	14
					24.5	6.8	10.9	13.8	3.8–13.6	9.2	6.6	164	140	15
6					26	7.7	12.3	15.6	4.0–14.5	9.8	7.0	188	180	17
					28	8.9	14.3	18.2	4.5–15.5	10.6	7.5	212	230	20
	Sea heaps up, and white foam from breaking waves begins to be blown in streaks along the direction of the wind (Spindrift begins to be seen).	7	Moderate gale	28–33	30	10.3	16.4	20.8	4.7–16.7	11.3	8.0	250	280	23
					30.5	10.6	16.9	21.5	4.8–17.0	11.5	8.2	258	290	24
7					32	11.6	18.6	23.6	5.0–17.5	12.1	8.6	285	340	27
					34	13.1	21.0	26.7	5.5–18.5	12.8	9.1	322	420	30
7					36	14.8	23.6	30.0	5.8–19.7	13.6	9.6	363	500	34
	Moderate high waves of greater length, edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility	8	Fresh gale	34–40	37	15.6	24.9	31.6	6–20.5	13.9	9.9	376	530	37
					38	16.4	26.3	33.4	6.2–20.8	14.3	10.2	392	600	38
					40	18.2	29.1	37.0	6.5–21.7	15.1	10.7	444	710	42
8					42	20.1	32.1	40.8	7–23	15.8	11.3	492	830	47
	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong gale	41–47	44	22.0	35.2	44.7	7–24.2	16.6	11.8	534	960	52
					46	24.1	38.5	48.9	7–25	17.3	12.3	590	1110	57
	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes on a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected.	10	Whole* gale	48–55	48	26.2	41.9	53.2	7.5–26	18.1	12.9	650	1250	63
					50	28.4	45.5	57.8	7.5–27	18.8	13.4	700	1420	69
					51.5	30.2	48.3	61.3	8–28.2	19.4	13.8	736	1560	73
					52	30.8	49.2	62.5	8–28.5	19.6	13.9	750	1610	75
9					54	33.2	53.1	67.4	8–29.5	20.4	14.5	810	1800	81
	Exceptionally high waves. Sea completely covered with long white patches of foam lying in direction of wind. Everywhere edges of wave crests are blown into froth. Visibility affected.	11	Storm*	56–63	56	35.7	57.3	72.5	8.5–31	21.1	15	910	2100	88
					59.5	40.3	64.4	81.8	10–32	22.4	15.9	985	2500	101
	Air filled with foam and spray. Sea white with driving spray. Visibility very seriously affected.	12	Hurricane*	64–71	> 64	> 46.6	74.5	94.6	10–35	24.1	17.2	—	—	—

* For hurricane winds (and often whole gale and storm winds) required durations and reports are barely attained. Seas are therefore not fully arisen.

‡ Revised December 1964 by L. Moskowitz and W. Pierson. Used courtesy of The Navy Oceanographic Office

*U.S. GOVERNMENT PRINTING OFFICE: 1981-0-726-049/1...